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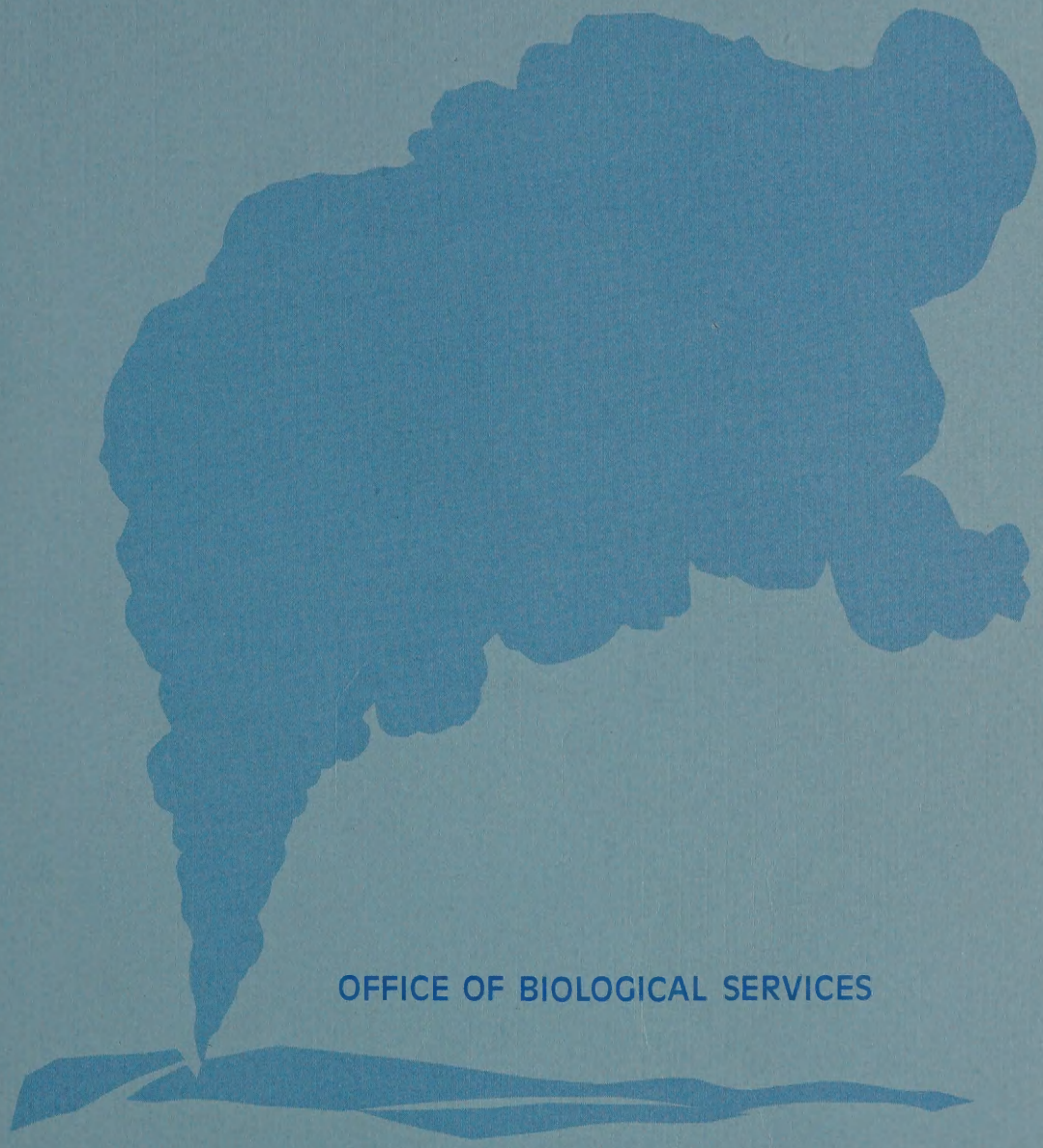
GEOTHERMAL HANDBOOK



OFFICE OF BIOLOGICAL SERVICES

GEOTHERMAL PROJECT

1976

DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE

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GEOTHERMAL HANDBOOK

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INTRODUCTION

The Bureau of Land Management offered over 400,000 hectares (one million acres) for geothermal exploration and development in 1975, and the figure is expected to double this year. The Energy Research and Development Administration hopes for 10-15,000 megawatts of geothermal energy by 1985, which would require leasing over 16.3 million hectares (37 million acres) of land, at least half of which is federal land. Since there is an 8 to 8-1/2 year time lag between initial exploration and full field development, there would have to be a ten-fold increase in the amount of federal land leased within the next three years. Seventy percent of geothermal potential, 22.3 million hectares (55 million acres), is on federal lands in the west. The implications for the Service are enormous and the problems immediate.

Geothermal resources are so widespread they are found to some extent in most biomes and ecosystems in the western United States. In most cases exploitation and production of geothermal resources can be made compatible with fish and wildlife management without damage, if probable impacts are clearly understood and provided for before damage has unwittingly been allowed to occur. Planning for site suitability and a concern with specific operating techniques are crucial factors. There will be opportunities for enhancement: during exploration and testing many shallow groundwater bodies may be penetrated which might be developed for wildlife use. Construction equipment and materials needed for enhancement projects will be available in areas heretofore considered remote by land managers. A comprehensive knowledge of geothermal development is necessary to avoid dangers and seize opportunities.

This handbook is intended to serve as a working tool in the field. It anticipates where geothermal resource development will occur in the western United States in the near future. A set of environmental assessment procedures are presented which will allow the Service to provide input to the federal leasing process. As an impact information source by which to judge the appropriateness of a specific activity at a specific site, a discussion of activities-impacts is provided on a phase by phase basis. Mitigation and possible enhancement techniques are also presented so that the impacts of the development can be dealt with and the fish and wildlife situation improved.

The Service can achieve its objectives only if biological input is made throughout the entire process of geothermal development, from exploration to testing to full field operation. A discussion of geothermal leasing procedures emphasizes the timing and nature of Service participation in current interagency lease processing, and there is a provision for the utilization of new knowledge, techniques, and responses as experience is accumulated.

CHAPTER 1

GEOTHERMAL RESOURCE DEVELOPMENT

This description of geothermal resources in the western United States presents the basic geologic, physical, and chemical character of geothermal resources. Because of its brevity, this account is primarily qualitative. Some quantitative information is also included, however, in order to give an idea of the magnitudes of geothermal fluids that might be produced under various types of utilization, and their physical and chemical properties. It is stressed that quantitative data are included only as examples of what may be expected, and are not to be regarded as definitive. Precise prediction of the compositions, temperatures, enthalpies, and volumes of geothermal fluids that may be produced in different regions is generally not possible.

A comprehensive glossary, covering the most common terms encountered in discussion of geothermal resources, is at the end of this section, and since individual terms usually are not defined in the text, the reader is urged to make use of the glossary.

Part I - The Nature of Geothermal Resources

Commercial development of high enthalpy (heat content per unit mass) geothermal resources is now limited to areas where shallow reservoirs of steam and/or hot water may be tapped by drill holes less than 3,050 meters (10,000 feet) deep. However, very shallow wells and natural surface discharge account for heavy private and commercial use of low enthalpy resources.

Geothermal reservoirs are formed by permeable rock in which steam or hot water is stored, and steam is present only if the reservoir is sealed off by impermeable rock. Either fractured non-porous rock or porous sedimentary rock may be permeable. Meteoric water that has infiltrated through faults and fractures, and been heated at depth, is generally the source of reservoir fluids.

The earth's interior is heated principally by the decay of radioactive elements (chiefly uranium and thorium) in the crust and upper mantle; some heat generated during the formation of the earth may still remain. This heat is transferred radially outward, mainly by convection and the ascent

of magma in the crust and upper mantle; in the uppermost part of the crust, convection in deep groundwater (convective water cells) transports heat to the surface. Conduction also occurs, but is less significant. The observed worldwide average increase in temperature with depth, or geothermal gradient, is about 18° - 26°C per kilometer (1°F per 70 to 100 feet). Therefore, given sufficiently deep drill holes, geothermal energy is potentially available anywhere.

Experimental technologies are currently exploring the feasibility of using the heat contained in impermeable dry rocks and in geopressure formations. However, commercial exploitation of geothermal energy presently requires 1) an abnormally high local geothermal gradient, 2) permeable rocks to serve as reservoirs, and 3) abundant hot water or steam to serve as a medium for storage and transfer of heat. Therefore the area over which geothermal energy can be economically utilized is severely limited.

Geothermal gradient is elevated above the world average within the major, active tectonic belts along the margins of tectonic plates. These include mid-ocean ridges and oceanic rises, subduction zones, and rift zones. Such belts are characterized by intense seismicity and volcanism, and a crust weakened by faulting and fracturing. Geothermal flux, or heat flow, and temperature gradient are high in these belts principally because of up-welling, hot mantle material (plastic rock), the ascent of magma through crustal fracture, and frictional heating along faults. Geothermal gradient may reach to nearly 10 times the world average, or about 180° - 26°C per kilometer. The hottest regions are those in which silicic igneous rocks have crystallized deep within the crust during the last few million years; most economic geothermal resources are in such areas.

Geothermal reservoirs are of two basic types: dry-steam (or vapor-dominated) and hot-water (or liquid dominated). Certain reservoirs contain mixtures of steam and hot water in a continuum of varying proportions, but classification tends to emphasize the end members of the continuum. Dry-steam reservoirs are rare, probably comprising less than 10 percent of all economic reservoirs. Only three have been developed: The Geysers, California; Lardarello, Italy; Matsukawa, Japan. Significant electric power is generated at all three. Hot-water reservoirs contain fluids of widely varying enthalpy. Higher-enthalpy fluids may be used to generate electricity, while those of lower enthalpy must be used directly, as in space heating or for bathing (balneology). Most reservoirs used to generate electricity are and will be of the high-enthalpy, hot-water type.

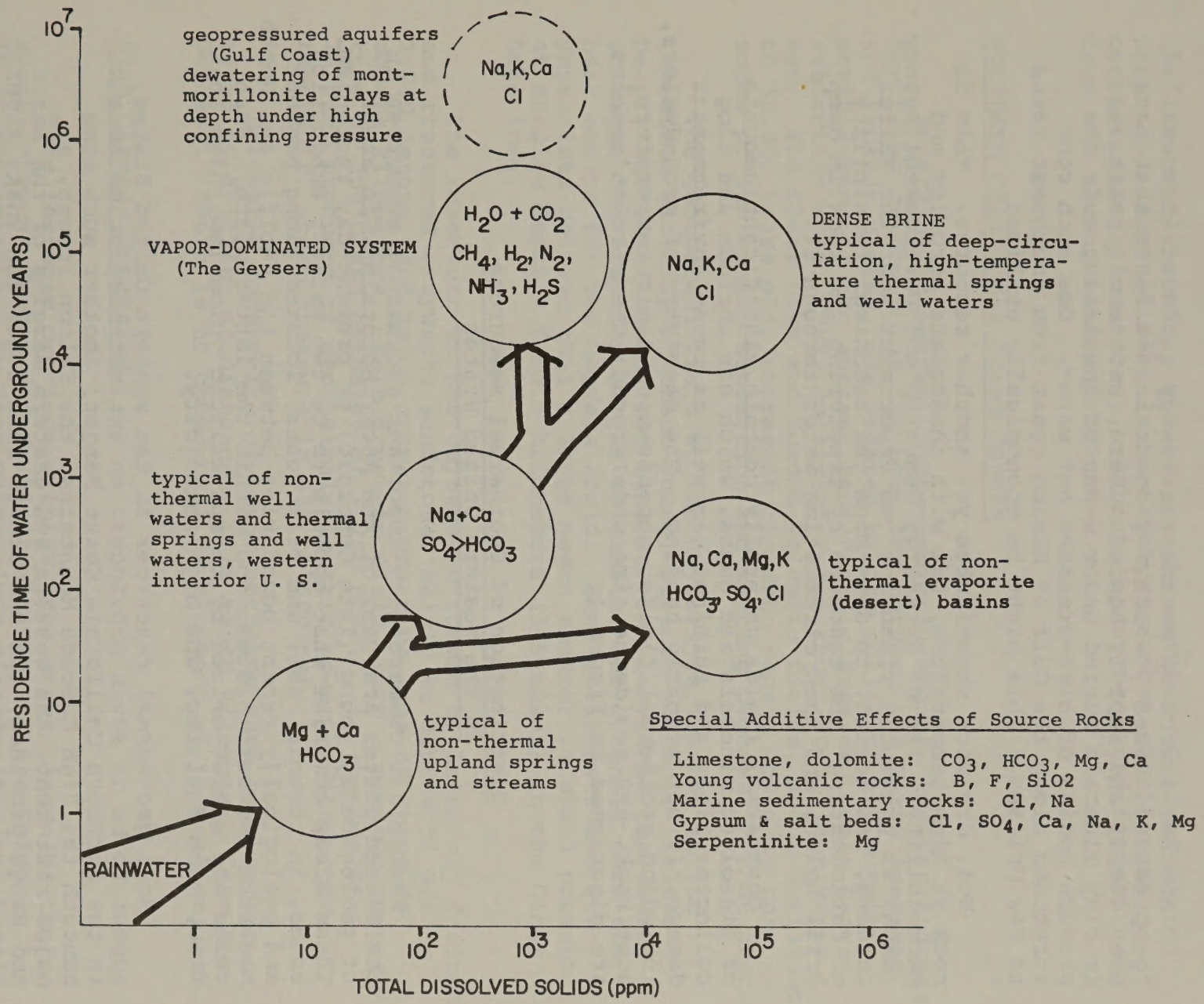


FIGURE 1 CHEMICAL EVOLUTION PATHS OF THERMAL AND NON-THERMAL GROUND WATERS, IN THE WESTERN UNITED STATES

Another source of geothermal energy is found in so-called "geopressured zones", which may occur in sediments that have been deeply and rapidly buried. Here, exothermic reactions in clay minerals buried under a cap of insulating muds can produce bodies of high-pressure hot water. One such zone stretches along the Gulf of Mexico coast from southwest Texas to New Orleans. This might be economically utilized.

Hot, dry rock constitutes yet another resource. This is rock at high temperature, but with inadequate porosity and permeability. The U. S. Energy Research and Development Agency (ERDA) is presently financing an experiment near the Valles Caldera, New Mexico, to determine the technical feasibility of "stimulating" the resource by fracturing the rock in deep drill holes, and then circulating water through it.

Geothermal fluids generally contain significant amounts of dissolved minerals and gases, which can corrode and clog collector lines and turbines, as well as cause environmental damage, if not properly handled. The chemistry of groundwaters, including geothermal fluids, depends upon their temperature, host rock, and residence time underground; these relationships are diagrammed in Figure 1.

Distribution of Geothermal Resources in the Western United States

Nearly all commercially important geothermal resources in the United States are west of the Rocky Mountains, in areas of geologically young (late Cenozoic) or present-day tectonism. These areas comprise what appears to be two extinct subduction zones, an oceanic rise, and rift zones, located along present and geologically recent boundaries between the Pacific and North American tectonic plates, and within the latter plate. Such zones are characterized by recent silicic volcanism, high heat flow, much faulting, and high seismicity.

Most geothermal resources in the western United States appear to be in seven provinces: an extinct subduction zone in the northern California Coast Ranges; another such zone beneath the High Cascade Mountains; the Salton Trough, a major rift zone; the western and eastern margins of the Basin and Range province; the Rio Grande rift zone; the Snake River Plain. (See Figure 2.)

East of the Rocky Mountains, the northern Gulf of Mexico Basin geopressured zone is certainly the most significant geothermal resource area, and has a nature quite different from the seven western provinces.

Northern California Coast Ranges

According to current plate-tectonic theory, the San Andreas fault, which now forms the boundary between the North American and Pacific plates, was created by the collision and mutual annihilation of the ancient East Pacific Rise and Coast Range subduction zone. This collision began about 30 million years ago. The Clear Lake and Sonoma Volcanic fields, about 6 million to 50,000 years old, represent the most recent volcanic episodes of the waning subduction and melting process in that area.

The geothermal field at The Geysers is located in the immediate vicinity of these young, silicic volcanic fields. Deeply buried masses of hot igneous rock served as the source of magma for eruption of the volcanics, and probably form the heat source for The Geysers field. Some geologists and geophysicists believe that a large magma chamber is still present at shallow depth 4.8 to 8 kilometers (3-5 miles) in the Clear Lake Area.

The reservoir at The Geysers is formed by intensely faulted and fractured greywacke sandstone, mainly at depths of 900 to 2,750 meters, and has a proven productive area of about 50 square kilometers. This drysteam field, with a maximum temperature of 250°C and enthalpy of 1,200 BTU/lb, is the world's largest producer of geothermal-electric power. Within the reservoir, steam pressure is 450 to 500 psi.

Hot-water reservoirs of lower enthalpy have been encountered by drilling at distances of 19 to 40 kilometers from The Geysers. There is no commercial development at these locations.

High Cascade Mountains

This tectonic province extends from Mount Lassen on the south, through Oregon and Washington, into British Columbia. It is characterized by vast outpourings of andesitic and basaltic lavas from 2 to 10 million years old, and many recently active volcanoes, such as Lassen, Shasta, Hood, Baker, St. Helena, and Three Sisters. The intense volcanism often is attributed to the presence of a waning subduction zone at depth.

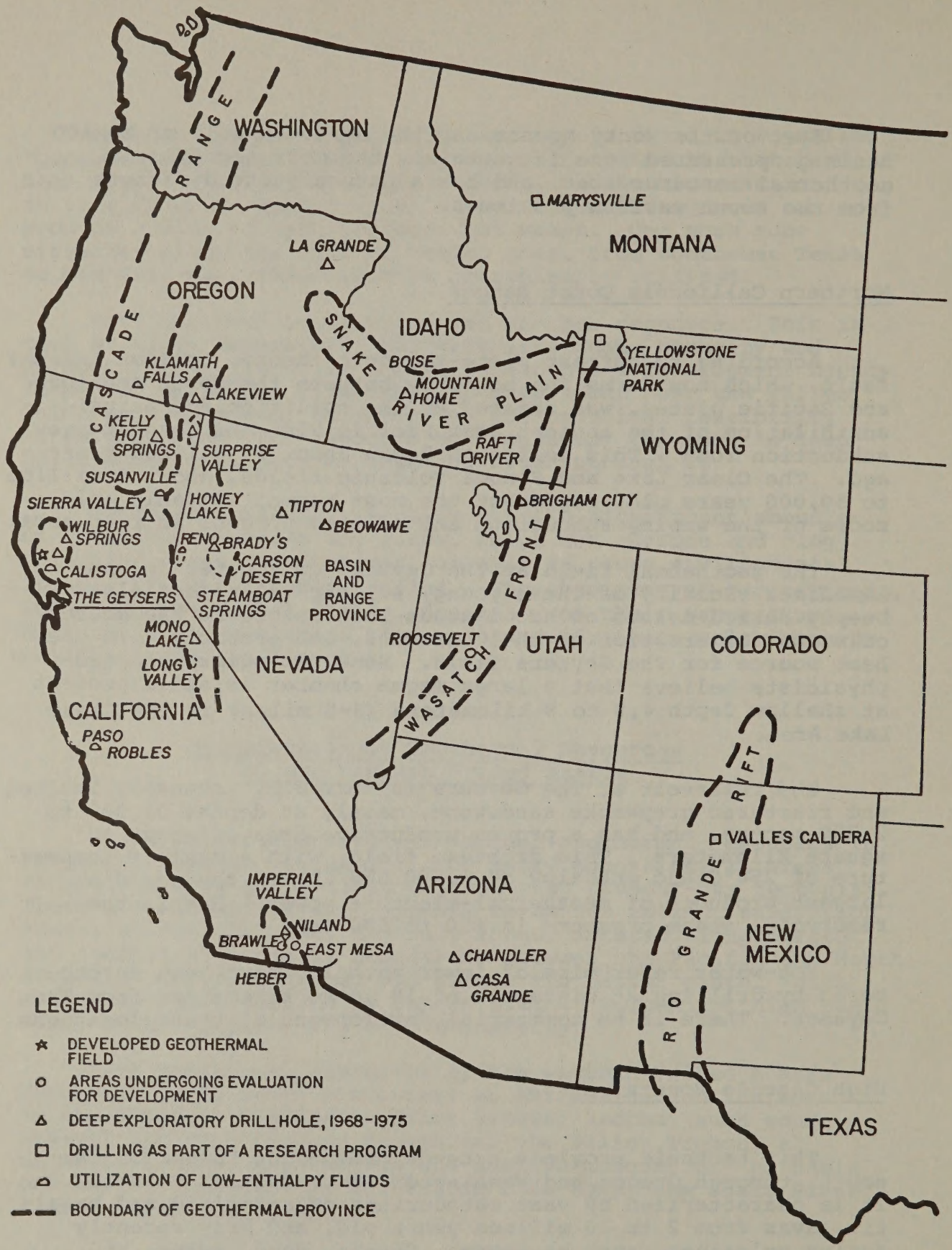


FIGURE 2 GEOTHERMAL EXPLORATION AND DEVELOPMENT IN THE WESTERN UNITED STATES 1968-1975,

There are insufficient data to characterize the geothermal resources of this belt. Fumaroles are present in Lassen National Park; however, lands designated as national parks are withdrawn from mineral extraction or other resource development. High-enthalpy hot-water reservoirs may exist elsewhere in the range. At Klamath Falls, Oregon, a low-enthalpy hot-water reservoir is used for heating of homes, schools and businesses. Exploration is continuing at a modest pace in the California and southern Oregon portions of the belt.

Salton Trough

After the Geysers, the next most important geothermal area in the United States, in terms of commercial potential, is in the Salton Trough, or Imperial Valley region. This lies at the northern end of the major rift zone extending the entire length of the Gulf of California, along which the Pacific and North American plates have been pulling apart for the past 3 million years. The East Pacific Rise also extends through the Gulf into the Salton Trough, where the mantle is only 19 kilometers deep. High heat flow from the hot, shallow mantle beneath the Rise, together with the faulting and fracturing due to rifting, have combined to generate silicic volcanism and high geothermal gradients in the region.

There appear to be four or more geothermal reservoirs in the Imperial Valley, containing hot brines of different character: a high-temperature (300°C), high-enthalpy (450 BTU/lb), high-salinity (250,000 ppm total dissolved solids [TDS]) brine, at Niland; and three other reservoirs with fluids of lower temperature (up to 200°C), enthalpy, and salinity (15,000-25,000 ppm TDS) at Brawley, Heber, and the East Mesa. Each of these reservoirs is in fractured sandstones of youthful geologic age. Exploration is very active at Brawley, Heber, and East Mesa. However, there has been no commercial development, for reasons explained in the section on utilization. At Cerro Prieto, Mexico, 32 kilometers south of the border, a 75 megawatt geothermal power plant has been in operation since 1973 and a second 75 megawatt plant is currently under construction. Cerro Prieto is a part of this same geothermal province, and is characterized by high temperature and enthalpy, with lower salinity of 17,000 ppm TDS.

Basin and Range Province

Two major geothermal belts extend along the eastern and western margins of the Basin and Range province, one in California, Nevada and Oregon, the other in Idaho and Utah. Geothermal fields or prospects also occur between these belts in Nevada, and far to the south in southern Arizona.

Many geologists and geophysicists believe that the East Pacific Rise extends northward from the Salton Trough into west-central Nevada, where it forms an active spreading center, giving rise to the tensional faulting and high seismicity that characterize the Basin and Range province. Young silicic and basaltic volcanism and faulting are concentrated along the eastern and western margins of the province, for reasons that are not well understood.

The western belt extends from Lakeview, Oregon, through Surprise Valley and Long Valley, to Coso, California, for a distance of some 560 kilometers; it has a maximum width of 130 kilometers in the vicinity of Reno, Nevada, where it extends eastward across the Carson Desert. Geothermal reservoirs here appear to be entirely of the hot-water type. Exploration has kept a steady pace over the past 10 years, and will probably continue to do so. Electric power may be generated eventually in a few places, but immediately development is likely to be in the expansion of existing direct-heating applications.

The eastern belt lies just west of the Wasatch Front, which is the faulted boundary between the Basin and Range province and the Colorado Plateau-Rocky Mountains. This belt extends north-south across the entire state of Utah and into southern Idaho, for a distance of some 560 kilometers; its width is about 100 kilometers. Geologically, the belt is similar to the western one described above; however, some geothermal reservoirs here may have higher enthalpy. Exploratory drilling at Roosevelt Hot Springs indicates a high-enthalpy hot-water reservoir that might be of commercial quality (for electric power generation) and quantity. Intensive exploration is likely to continue for several years in the region.

Another important geothermal area in the center of the Basin and Range province is Beowawe, Nevada, where hot water at over 200°C has been encountered in drill holes. The reservoir is probably quite small. Other prospects have been drilled in Nevada, Oregon and Arizona, and still others in these states and New Mexico are being explored.

Rio Grande Rift

The Rio Grande Rift is up to 160 kilometers wide, and extends northerly from the vicinity of El Paso, Texas to central Colorado, for a length exceeding 650 kilometers. Tensional faulting, basin subsidence, and repeated intrusion and extrusion of young, silicic and basaltic igneous rocks characterize this zone.

A number of potentially valuable prospects occur in this zone, and a commercial-grade reservoir probably exists at the Valles Caldera, New Mexico. This hot-water system has a temperature above 260°C, but is of unknown size. It is believed that a small power plant will be in operation by 1980. Exploration in this zone continues at a moderate pace, but may increase if commercial production is achieved at Valles Caldera.

Snake River Plain

Vast quantities of young basalts cover the Snake River Plain of Idaho and Oregon. These were probably erupted in response to deep-seated rifting. Limited exploration suggests that geothermal resources here are not of high enthalpy, but may be quite extensive. Low-enthalpy warm and hot waters have been found, and are used for space heating in Boise, Idaho. Deep exploratory drilling in the Raft River Valley (southern Idaho) has penetrated a 150°C reservoir at a depth of 1,525 meters.

Northern Gulf of Mexico Basin

This basin contains an extremely thick sequence (up to 15,250 meters) of Tertiary sediments, and extends in a 3,220 kilometer arc from the Yucatan to the Florida Peninsula. It forms a part of the Gulf Coast geosyncline (Figure 3).

Beds of alternating muds and sands are buried by thousands of meters under subsequently deposited material. Due to differential settling of the varying material, faults have isolated the buried beds. Because the mud layers prevent the migration of water trapped in the lower sand beds, the normal geothermal heat flow is trapped, causing a significant heat zone, and the weight of the overlying sediments causes that trapped hot water reservoir to be under unusual pressure. The diagenesis of the clays of the mud layers results in the slow migration of low saline water from these beds to the sand beds. This mixing

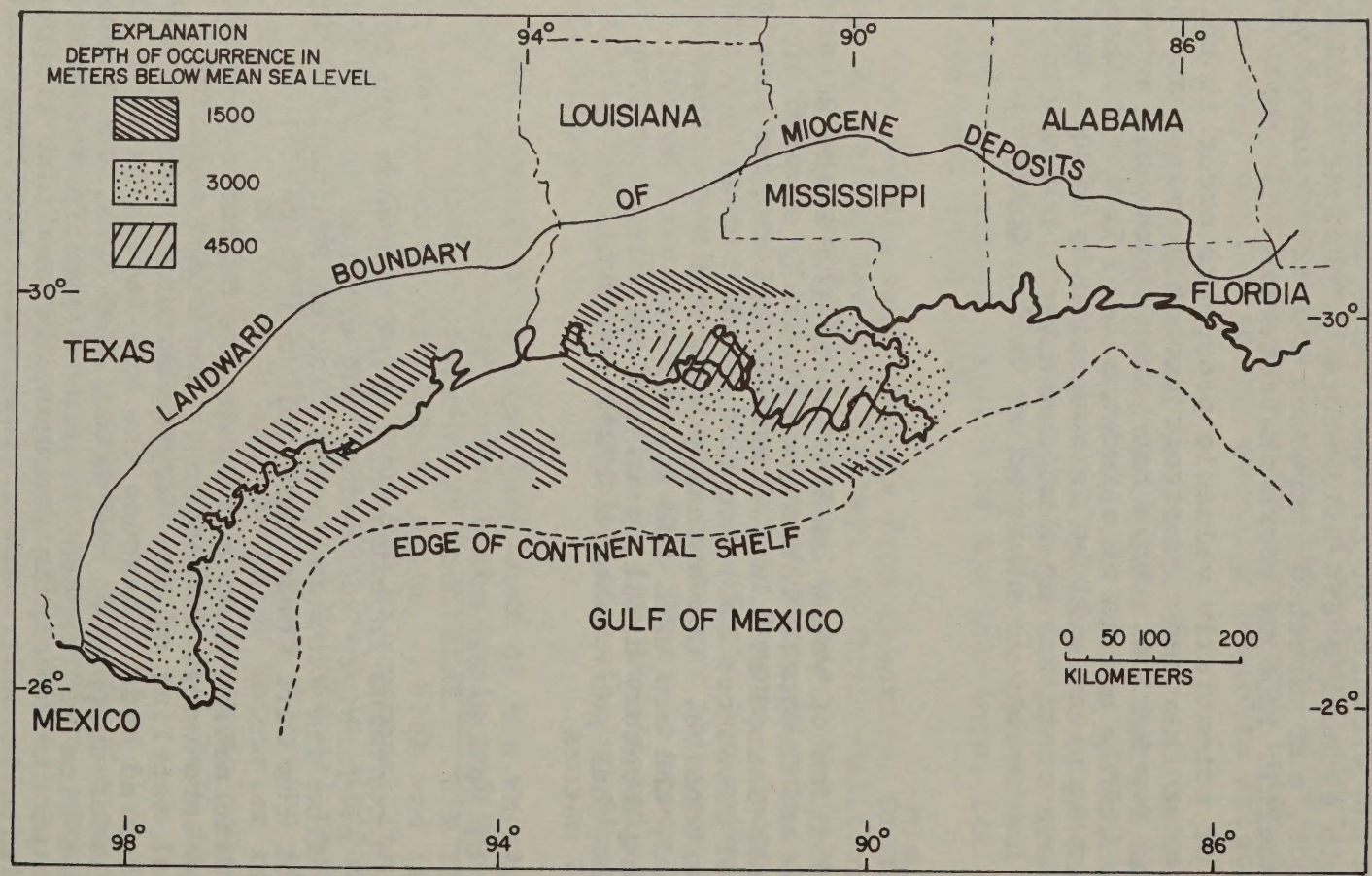


FIGURE 3 LOCATION AND DEPTH OF THE GEOPRESSURED ZONE, NORTHERN GULF OF MEXICO BASIN
(FROM JONES, 1970)

of the water causes the geothermal water to be lower in total dissolved solids than the originally trapped water, waters found in the sediments above the geopressure zone, and in the overlying sea water.

The geopressure belt extends from the mouth of the Rio Grande River to that of the Mississippi, and lies at depths greater than 1,500 meters below sea level. Within geopressured deposits, temperature gradients may reach 1°C per 10.4 meters. The 120°C isotherm corresponds generally with the top of the belt, and the maximum observed temperature is 273°C at a depth of 5,800 meters. Water in these deposits ranges from 3,000 - 20,000 ppm TDS. Potential yields may be as high as 9,500 cubic meters of superheated water per day per well.

Utilization of Geothermal Resources

Geothermal energy may be used either to generate electricity or simply as a direct source of heat. Because heat dissipates rapidly, geothermal fluids cannot be transported far from their point of recovery without severe losses. The maximum transport distance depends on the initial enthalpy of the fluid and the intended use. For steam used to generate electric power, the probable maximum distance is 1.5 to 3 kilometers; hot water for agricultural use or space heating can be transported much farther, the greatest reported distance being 19 kilometers, with tests of up to 40 kilometers, in Iceland. Costs of pipeline and insulation in relation to the costs of other energy sources may serve as a limiting factor in many instances.

Conversion of heat to electricity is a practical means of moving geothermal energy from remote fields to population centers. However, this entails substantial loss of energy in conversion, transmission, and reconversion to do thermal or mechanical work. For these and other reasons, direct utilization (i.e. without conversion) is likely to increase in such applications as space heating, agriculture, industrial processing, and desalination, particularly as the cost of fossil fuels continues to rise. If other energy costs rise sufficiently, new communities may develop near geothermal fields.

Only a small fraction of the world's geothermal reservoirs have an enthalpy high enough for economical use in electric power generation, and this is also true of the western United States.

Generation of Electricity

There is presently much greater risk in finding and proving economic geothermal energy sources than there is in using fossil or nuclear fuels. Thus, until risk is reduced by new exploration techniques, capital-intensive development of geothermal energy is likely to proceed slowly.

In generating electricity, geothermal steam or hot water is used to run a heat engine (usually a steam turbine) connected to a generator. Chiefly for economic reasons, though for considerations of resource conservation and pollution as well, the efficiency of conversion of geothermal heat to electricity is a critical matter. The amount of electricity that can be generated per unit weight of geothermal fluid produced is the key parameter. This is closely connected with the capital and operating costs per unit of generating capacity, as well as with the amount of fluid (water, steam, minerals, and gases) and waste heat that must be handled. Total cost, which includes that for exploration, field development and maintenance (of wells and collector lines), power plant construction and maintenance, and pollution control must be competitive with that for other fuels (nuclear or fossil). Dry steam generating systems have a distinctly lower cost per kilowatt hour (kwhr) than fossil fuel or nuclear fired plants. Flashed steam and binary cycle systems have higher costs than dry steam systems. For proven fields flashed steam systems are still competitive with fossil and nuclear fired plants. Binary cycle systems still are in the research and development phase.

Dry steam systems pipe steam directly from deep wells through collector lines into steam turbines at the generating plant. The dry steam geothermal field at The Geysers appears to be the world's largest, and has the world's largest geothermal electric generating system, with an installed capacity of some 500 megawatts (mW). About 1,000 mW should be in service by 1978, and estimates of maximum sustainable yield run to 2,000 mW or more. Some 50 to 60 deep wells (from 1,200 to 3,000 kilometers deep) supply 10 million lbs per hour of steam to 11 generating plants. Steam enters the plants with temperature and enthalpy of 175°C and 1,200 BTU/lb, respectively, at a pressure of just under 100 psi. Steam is consumed at a rate of 20 lb/kwhr. About 80 percent of the steam is evaporated in cooling towers, while the remaining 20 percent is condensed. This condensate contains several hundred ppm of boron and ammonia, and is reinjected into the reservoir through disposal wells. Reinjection minimizes environmental pollution and helps to maintain reservoir pressure and recharge, thus prolonging production lifetime, which is now estimated at some 30 years.

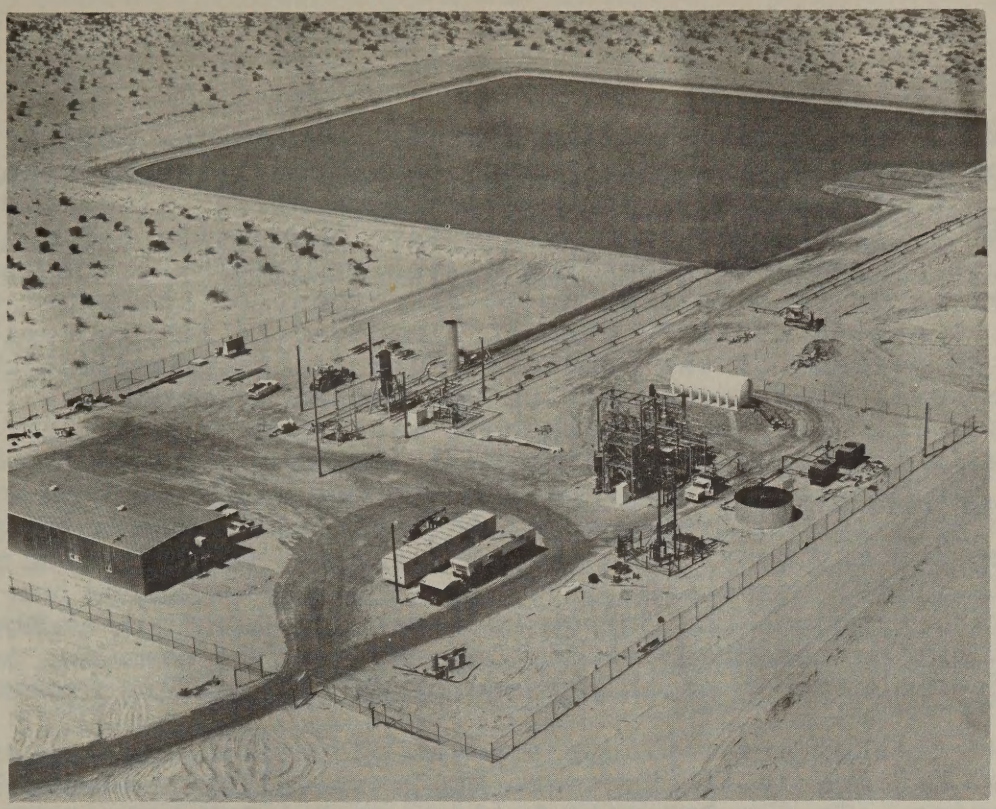


Photo Courtesy U. S. Bureau of Reclamation

U. S. Bureau of Reclamation geothermal fluid desalination research facility at East Mesa, Imperial Valley, CA.

Photo Courtesy Pacific Gas and Electric Company

Twin unit generating facility at The Geysers, CA.

Most geothermal electric systems, worldwide, however, are and probably will continue to be of the flashed steam type. In this process, hot reservoir water (usually at 200° to 315°C) flash boils as it flows into deep wells and confining pressure decreases. Depending on the wellhead pressure and initial water temperature, up to 35 percent of the water will flash to steam; 15 to 20 percent flashover is fairly typical. About 80 percent of the produced fluid is therefore not used in the power plant, and must be reinjected or otherwise disposed of. Because so much heat is wasted, thermal efficiency in flashed steam plants is only about 3 percent. Worldwide, minimum temperature and enthalpy of water used in such plants are, respectively, about 180°C and 350 BTU/lb; fluid consumption may be as much as 300 lb/kwhr. At this time the electrical conversion of lower enthalpy waters is uneconomic, although the Energy Research and Development Agency is conducting research and development in this area due to the great abundance of this resource in the western United States.

No flashed steam plants are yet operational in the United States, but one is likely to be built at Valles Caldera, in New Mexico. In the Imperial Valley, at Brawley, the East Mesa and Heber Reservoirs have maximum temperatures of 200°C and salinity in the range of 15,000-25,000 ppm TDS. These reservoirs probably form a major resource, but, although exploration is continuing, development has come to a standstill pending resolution of problems of binary cycle generation, equipment corrosion and scaling, waste disposal, and land subsidence. At Cerro Prieto, Mexico, about 32 kilometers south of Imperial Valley, a flashed steam plant now generates 75 mW.

Another method of generating electricity from geothermal hot water utilizes the binary cycle (also called the vapor turbine cycle). In this, the hot water is pumped from production wells through a heat exchanger at reservoir pressure, and then pumped back into the reservoir through reinjection wells. In the heat exchanger, the hot water gives up heat to a low-boiling-point fluid such as butane or freon, which drives a low-pressure turbine. Although development of this process is in its infancy, and it is not yet in use in the United State, it could have several major advantages over the flashed steam system. It appears to be more efficient (i.e. obtains more power output per pound of water produced); wells, collector lines, and turbines may suffer less wear; reinjection of <u>all</u> produced fluid eliminates problems of waste water and gas disposal, helps to maintain reservoir pressure (hence enhancing production lifetime), and assures minimum land subsidence. Because it appears to be more efficient, the binary cycle might economically utilize lower-enthalpy waters; however, its greater capital costs would tend to offset this advantage.

An independent supply of cooling water is required for the binary cycle. Field testing of components for binary cycle systems is to begin this year in the Imperial Valley at Niland with San Diego Gas and Electric Company's 10 megawatt facility.

Direct Utilization

Geothermal energy has not been used widely in direct application in this country, both because the resource generally is remote from population centers, and because of formerly low prices for fossil fuels. Water whose temperatures and enthalpy are too low for economic use in electricity generation may be economically used in direct applications. Morever, direct use requires a smaller capital investment and has greater efficiency, utilizing more heat per unit of produced fluid.

Space heating, greenhousing and balneology are the most widespread direct applications, both worldwide and in the United States. Iceland pioneered municipal heating using geothermal water; 50 percent of its 200,000 population live and work in geothermally heated homes and offices. In the United States, geothermal waters are used in varying degree for space heating in such places as Klamath Falls, Oregon; Boise, Idaho; Susanville, California; and the Reno-Steamboat Springs area, Nevada. Space heating and commercial uses in these areas may grow rapidly, especially in Boise and Susanville, which have federal grants for research and development.

Greenhousing is a rapidly growing application around the world, and, in the western United States has found limited use at Calistoga and Wendel Hot Springs, California, and Lakeview, Oregon, among other places. Water whose wellhead temperature is as low as 60°C is useful in space heating and greenhousing, and there are many areas where hot springs and shallow wells (a few tens to hundreds of meters deep) produce water at least that hot.

Industrial and agricultural applications are potentially numerous. Below-boiling waters may be used in simple process heating, refrigeration, warming of soil in the open, and fish farming. Above-boiling waters may be used in distillation, desalination, and to provide process steam. For example, in New Zealand, geothermal steam is used directly in paper manufacturing.

Hot springs and warm mineral springs have been used for recreation and health in many countries since ancient times. In the western United States there are many resorts at such springs, and these are particularly numerous in northern California.

Exploration Practice in the Western United States

The objectives of any geothermal exploration program are 1) to locate areas underlain by hot rock (the heat source); 2) to estimate the location, depth, volume, temperature, and permeability of the reservoir rocks and the amount of fluid in storage; and 3) to determine whether wells will produce dry steam, hot water, or a mixture of both, as well as the chemical composition of the produced fluid. In the western United States, exploration techniques utilize methods of geology, hydrology, geophysics, and geochemistry, which vary according to the area investigated and the investigator's preferences. Exploration usually begins with compilation of available data from published literature and proprietary sources. This first phase usually involves a large region, perhaps hundreds or even thousands of square kilometers. Reconnaissance field work follows, to obtain important data on geology and geochemistry unavailable in any other way. This is usually for several closely related prospects that tentatively were selected in the first phase. As this phase identifies the more interesting prospects, detailed geophysical and geologic, and possibly geochemical, field work in the most interesting prospects is undertaken (third phase). The fourth and final phase is deep exploratory drilling in the best prospect(s).

Geology

Regional geologic data are first collected in order to define the thermal areas geographically. Geologic data are useful in locating probable heat sources (hot rock). The age and distribution of young igneous rocks, hydrothermally altered rocks, and hot spring deposits such as sinter and travertine are especially useful. Distribution of young faults is valuable information because reservoirs often occur in rock which has been recently faulted, or is presently undergoing active faulting, and because recent faults often serve as conduits for the movement of meteoric water down into reservoirs and of thermal fluids up to the surface.

Data on the temperature, discharge, and chemistry of springs and wells, as well as on the extent and flow of ground water, often are collected early in exploration. Temperature and chemistry of hot springs are critical data in the initial assessment of a prospect. Aerial photography, and infrared and radar imagery from satellites, can be useful in locating faults and abnormally warm ground.

Detailed geologic mapping becomes necessary later in the exploration program to allow interpretation of detailed geophysical data and to provide closer control for selection of drilling sites.

Geophysics

Electrical and electromagnetic surveys of deep resistivity are useful in delimiting a geothermal reservoir because hot, mineralized reservoir fluids are electrically very conductive. Thus, most exploration programs utilize direct-current surveys, electromagnetic soundings, and sometimes magnetotelluric soundings of deep resistivity (to depths of 8 kilometers). These techniques are slow and costly, and therefore are carried out in detailed surveys of particular targets, rather than in reconnaissance phases of exploring large areas.

Passive seismic methods are often used to locate reservoirs. These surveys record and locate microearthquakes and seismic noise, which may be unusually frequent and intense in geothermal reservoirs. Practice has been to use passive seismic surveys early in the exploration sequence, either as a reconnaissance technique or as the first detailed method. Active seismic methods are seldom used.

If a prospect remains attractive after reconnaissance exploration has been carried out, exploration programs always include drilling of shallow (to 100 or even 150 meters) holes for measurement of temperature gradient. This is the most direct means of obtaining subsurface temperatures. Such gradients commonly are projected to greater depth, as a means of estimating deep reservoir conditions.

Aeromagnetic and ground magnetic surveys, as well as gravity surveys, can be useful in interpreting subsurface geologic structure, but usually cannot be used to pinpoint a prospect. Therefore, such data usually are collected in early or reconnaissance stages of exploration.

Resistivity, seismic, and temperature-gradient surveys require road access into the prospect area, because the equipment used is not easily portable. Resistivity and seismic recording gear can be back-packed for short distances, but resistivity transmitting equipment (large generator and switching gear), and drill rigs demand road access. The configuration of these surveys is controlled by the location of pre-existing roads; road construction for such surveys apparently is uneconomic.

Geochemistry and Hydrology

Geochemical reconnaissance involves sampling and analyzing waters and gases from hot and cold springs and fumaroles. The data are then used to estimate 1) whether there is a thermal reservoir at depth, 2) whether the geothermal reservoir is hot-water or vapor-dominated, 3) the minimum temperature expected at depth, 4) the chemical character of deep waters, and 5) the likelihood and source of recharge water.

Chloride analyses can be used to discriminate between hot-water and vapor-dominated reservoirs. Concentrations of SiO_2 and ratios of Na-K-Ca are used to estimate minimum reservoir temperatures of hot-water systems. Variations in chemistry of nearby waters can be used in evaluating reservoir dimensions and composition, as well as nature of recharge.

Hydrologic data include measurements of discharge of springs, wells and streams. These data often serve as a baseline for calculation of possible effects on ground water by development of geothermal resources.

Geochemical and hydrologic exploration methods do not require road access.

Drilling

After surface exploration and shallow drilling methods have identified a potential commercial geothermal prospect, deep exploratory drilling is necessary to determine its true nature, thermal and chemical character, and producible energy. Only deep drilling can prove the commercial viability of a geothermal system. Often 2 or 3 wells, or even more, are needed before a reservoir can be determined to be commercially valuable. Vital data to be obtained are temperature-and pressure-versus-depth curves, lithology and stratigraphy, fluid composition, and rock permeability and porosity. These data, together with a full set of geophysical well-logs, and combined with production tests, will allow full evaluation of the prospect.

Drilling equipment is massive and heavy, and demands road access. Because drilling sites are very carefully chosen on the basis of data from preceding studies, it is often necessary to construct roads to these specific sites.

Drilling Practice

Geothermal reservoirs of large volume and moderate to high enthalpy, as required for electricity generation, are -enerally found at depths greater than 600 meters (2,000 feet) and may extend deeper than 3,000 meters (10,000 feet) in some places. Currently drilling costs limit maximum exploitable depth to 3,350 meters (11,000 feet). High-enthalpy fluids may sometimes exist at depths of less than a hundred meters, but the supply from such shallow sources is likely to be small. Large volumes of low-enthalpy water, suitable for many direct uses, may be found in shallow aquifers at depths less than 300 meters (1,000 feet), although deeper drilling may be required.

The deeper geopressured zones of the Gulf Coast are not presently exploitable. If the resource there is found to be of commercial value at a later date, drilling will probably proceed to depths of 3,600 to 4,575 meters (12,000 to 15,000 feet). Before such drilling takes place, there is likely to be testing of deep holes drilled previously in the search for oil or gas.

Shallow Exploration Wells

The drilling of shallow, slim holes to determine subsurface temperature gradients is indispensable in any detailed exploration program. A portable, truck-mounted, rotary drill rig is generally used for this type of hole. Hole depths are normally 60 to 90 meters (200 to 300 feet), although depths of 150 meters (500 feet) or more may be needed locally, to obtain measurements not disturbed by circulation of shallow groundwater. Diameter is usually 4 inches, sometimes less. The USGS and some states require that the casing in these holes be lined with drilling muds and cement and fitted with a valve to protect shallow groundwater and prevent blowouts.

Deep Exploration and Production Wells

Drilling methods. Geothermal wells, both for deep exploration and production, are generally drilled with standard rotary rigs as used for oil and natural gas (Figure 4). In rotary drilling, a drilling fluid must be circulated down through the drill stem in order to flush out the cuttings and protect the hole against collapse. This is usually a dense mud containing bentonite clay; at temperatures above 150°C, other compounds must be added to prevent gelling of the mud. Air is sometimes used as a drilling fluid, and good results have been obtained at The Geysers. Figures 5 and 6 are plans of typical drillsite equipment used for air and mud drilling.

Advantages of air drilling are high drilling speeds and low drilling costs (speeds 3 to 4 times greater; bit life 2 to 4 times longer, than with mud); no damage to production zone from clogging by circulating mud; drilling mud, which poses a disposal problem, does not have to be stored in a sump. Air drilling is unsuitable in formations bearing much water or with a strong tendency to slough. Reservoir formations must always be cooled while drilling (by the drill fluid) so that the hole temperature never exceeds the boiling point.

Rock formations in geothermal areas are generally fractured and faulted, causing frequent losses of drilling fluid; progress may, therefore, be much slower than in drilling for oil or natural gas. Drilling rates may be in the neighborhood of 30 to 60 meters (100 to 200 feet) per 24-hour day; thus a 1,800-meter (6,000-foot) deep well may take from several weeks to two months to complete. Cost of drilling ranges from $230 to more than $330 per meter. ($70 to $100 per foot).

Wells may be drilled directionally, in order to reach a desired subsurface position not directly beneath the drilling site. This may be necessary because of limited surface access or because production cannot be obtained by vertical drilling. However, the maximum practical horizontal reach of a well is probably less than 1,500 meters (5,000 feet).

Well diameters vary depending on the expected or desired rate of fluid flow, and are tapered from top to bottom. At The Geysers, typical wells taper from 30 inches at the surface to 8-3/4 inches in the production zone.

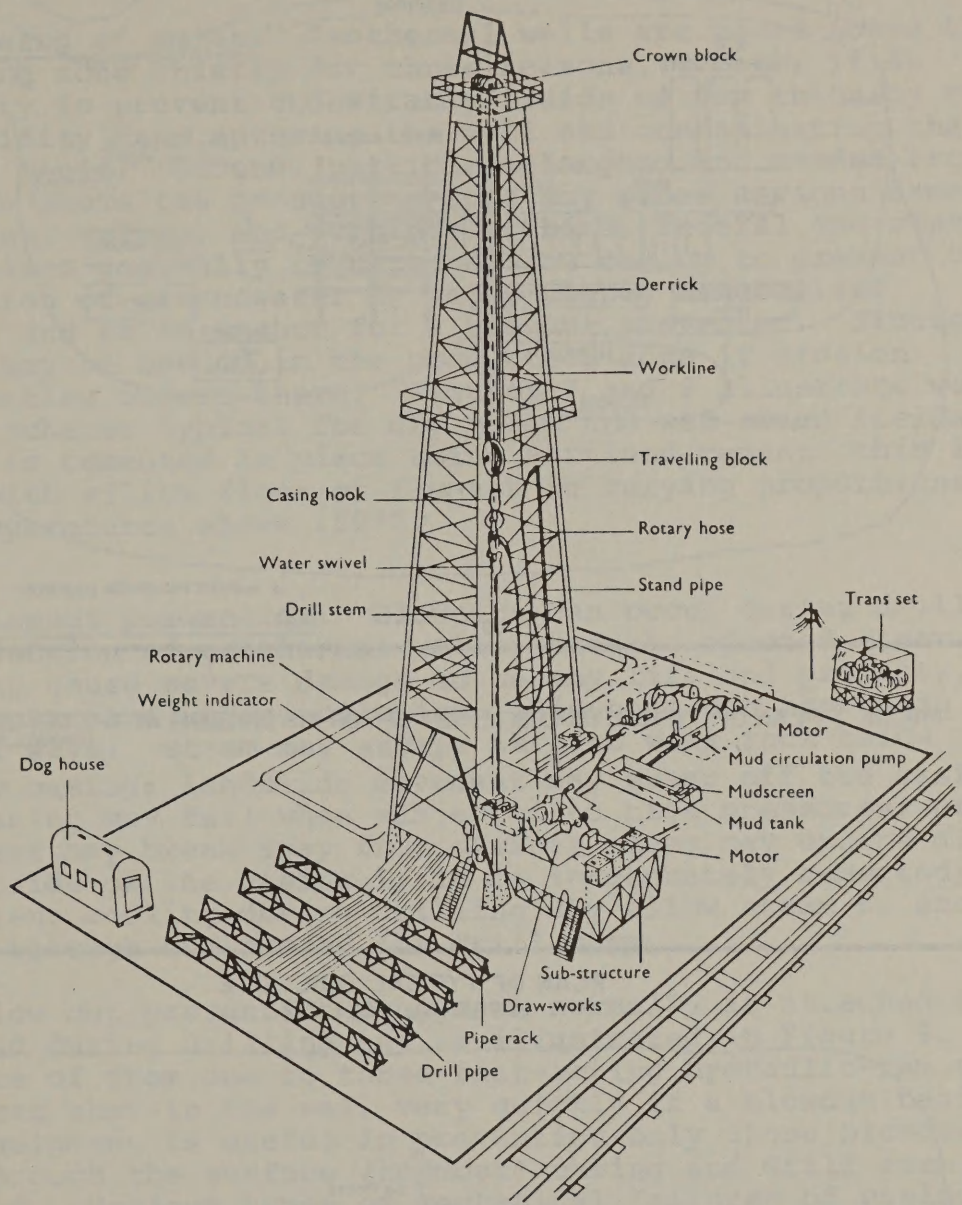


FIGURE 4 SCHEMATIC DIAGRAM OF ROTARY DRILLING RIG
(FROM: MATSUO, 1973, FIGURE 1)

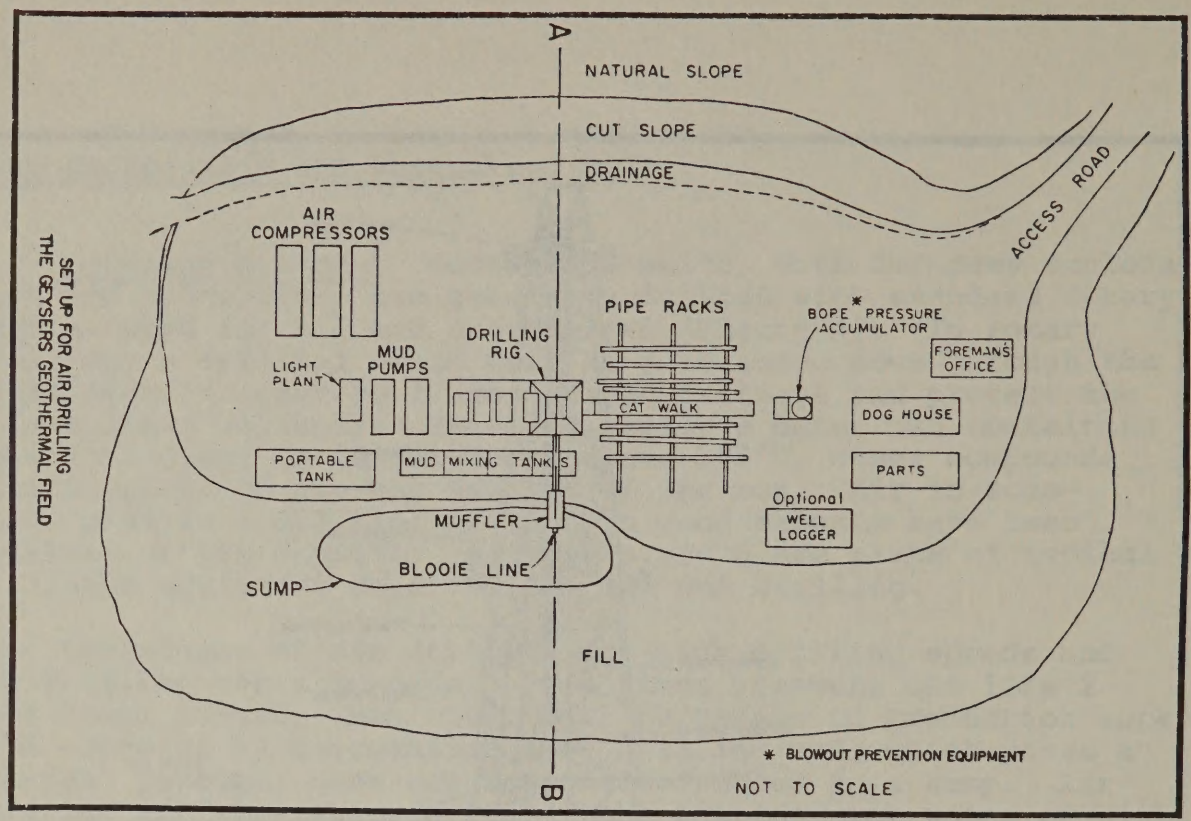


FIGURE 5 PLAN OF TYPICAL DRILLSITE, SET UP FOR AIR DRILLING AT THE GEYSERS
(CAMPBELL, 1974)

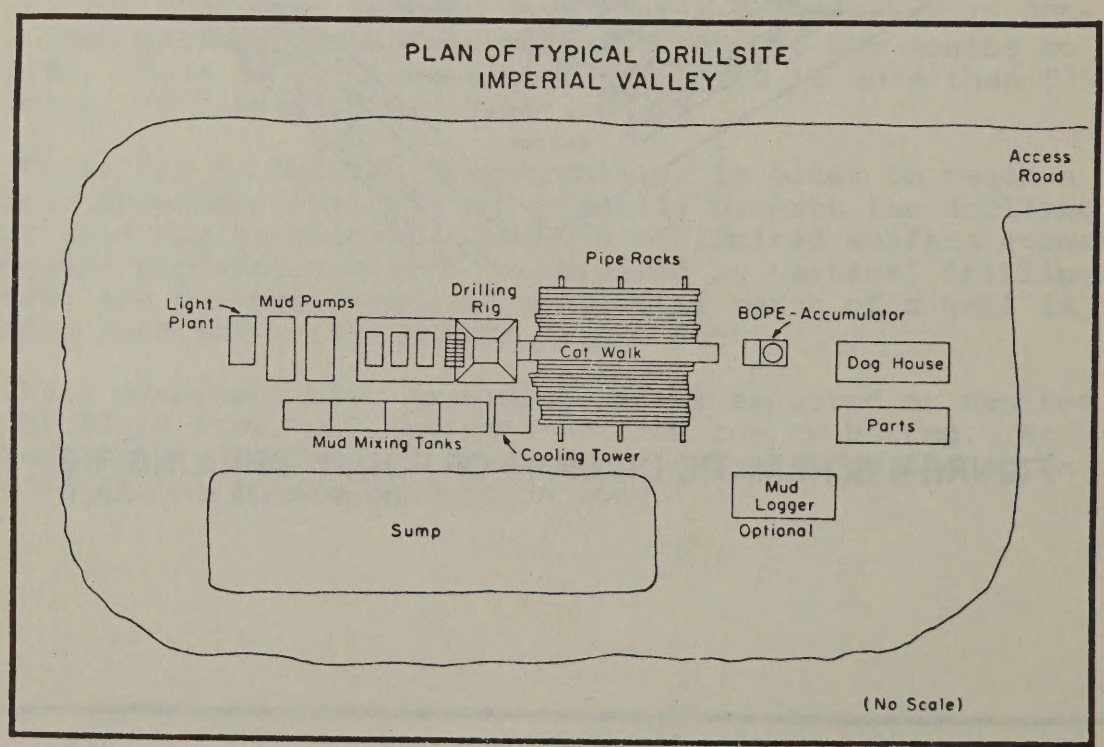


FIGURE 6 PLAN OF TYPICAL DRILLSITE, IMPERIAL VALLEY
(CAMPBELL, 1974, FIGURE 4)

Casing of wells. Geothermal wells are cased above the producing zone chiefly for three reasons. First, it is necessary to prevent undesirable fluids of low enthalpy or high acidity from entering the well and contaminating the desired fluid. Second, particles sloughed and eroded from the hole above the production zone may cause serious damage to piping, valves, and turbines. Third, federal and state regulations generally require shallow casing to prevent contamination of groundwater by deep, highly mineralized waters, and as an anchor for a blowout preventer. Slotted casing may be needed in the production zone if erosion or sloughing occurs there. Figures 7 and 8 illustrate well-casing schemes typical for dry steam and wet steam fields. Casing is cemented in place using Portland cement; this is mixed with silica flour or fly ash in varying proportions for temperatures above 150°C.

Blowout prevention. Blowouts can occur during drilling or production of geothermal wells, and the ejected steam and rock can cause severe damage to nearby life and property, as well as air and water pollution. Blowouts can happen in several ways: steam may escape through weak rock below shallow casing; landslide movement may shear off the casing; weak casing may fail when subjected to high pressures; wellhead equipment may break away from casing; steam may escape along the outside of the casing if it is inadequately cemented; insufficient cooling during drilling may allow steam to escape upward through and around the drill stem.

Blow-out prevention equipment normally is attached to the wellhead during drilling and is illustrated in Figure 9. This consists of from one to three fast-acting hydraulic-ram valves, which can shut-in the well very quickly if a blowout begins. Such equipment is useful in preventing only those blowouts that vent through the surface (topmost) casing and drill stem at the wellhead. Various types of mechanical failures of casing and wellhead equipment (listed above) can be prevented only by correct well-siting, drilling, and casing-installation procedures. The U. S. Geological Survey and many states have comprehensive regulations aimed at ensuring safe well-drilling and operating procedures for geothermal development activity on federal, state and private lands.

Productivity and spacing. Wells should be spaced close enough to maximize the rate of production from a given field, or portion of a field, and far enough apart so as not to interfere with each other. Wells are said to interfere when production from one well reduces production from a neighboring well. Optimum spacing is governed by the porosity and

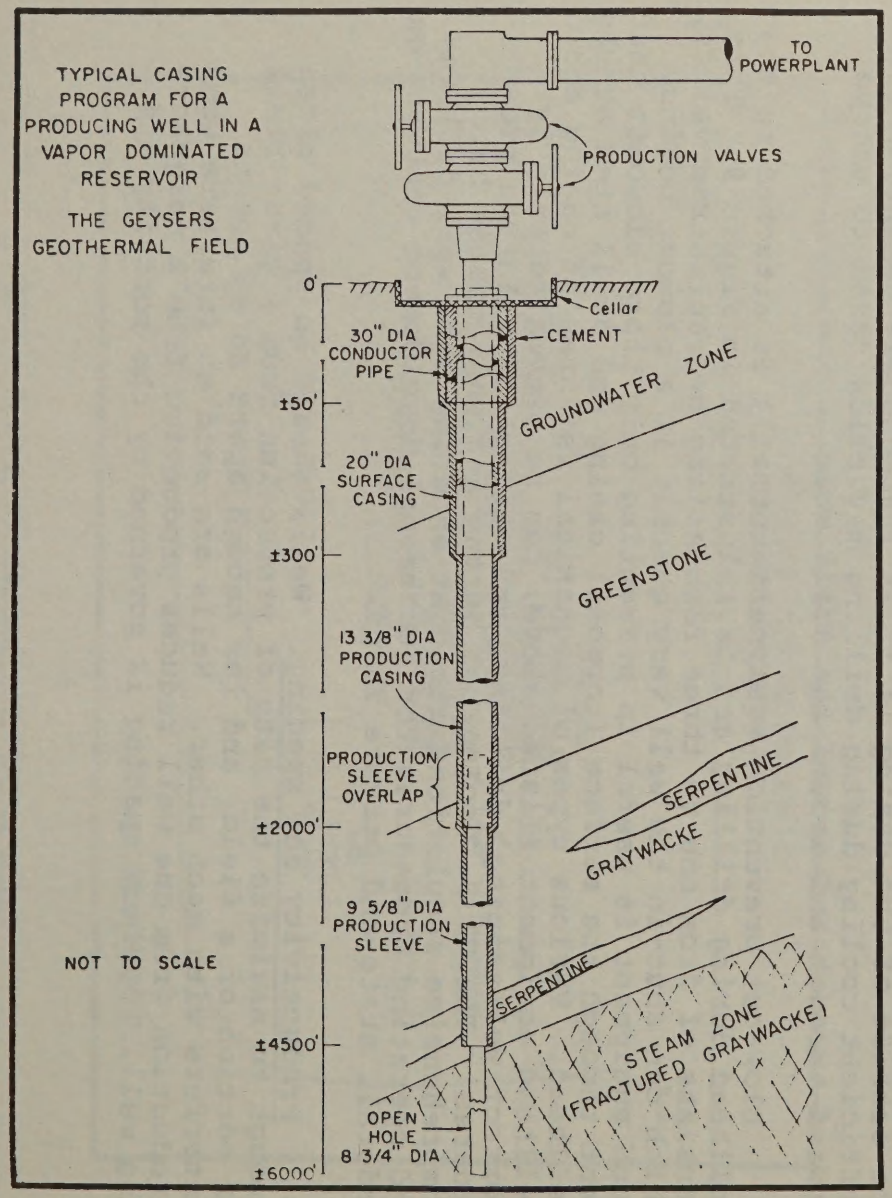


FIGURE 7 DIAGRAM OF TYPICAL WELL-CASING SCHEME FOR A PRODUCING WELL AT THE GEYSERS (CAMPBELL, 1974, FIGURE 12)

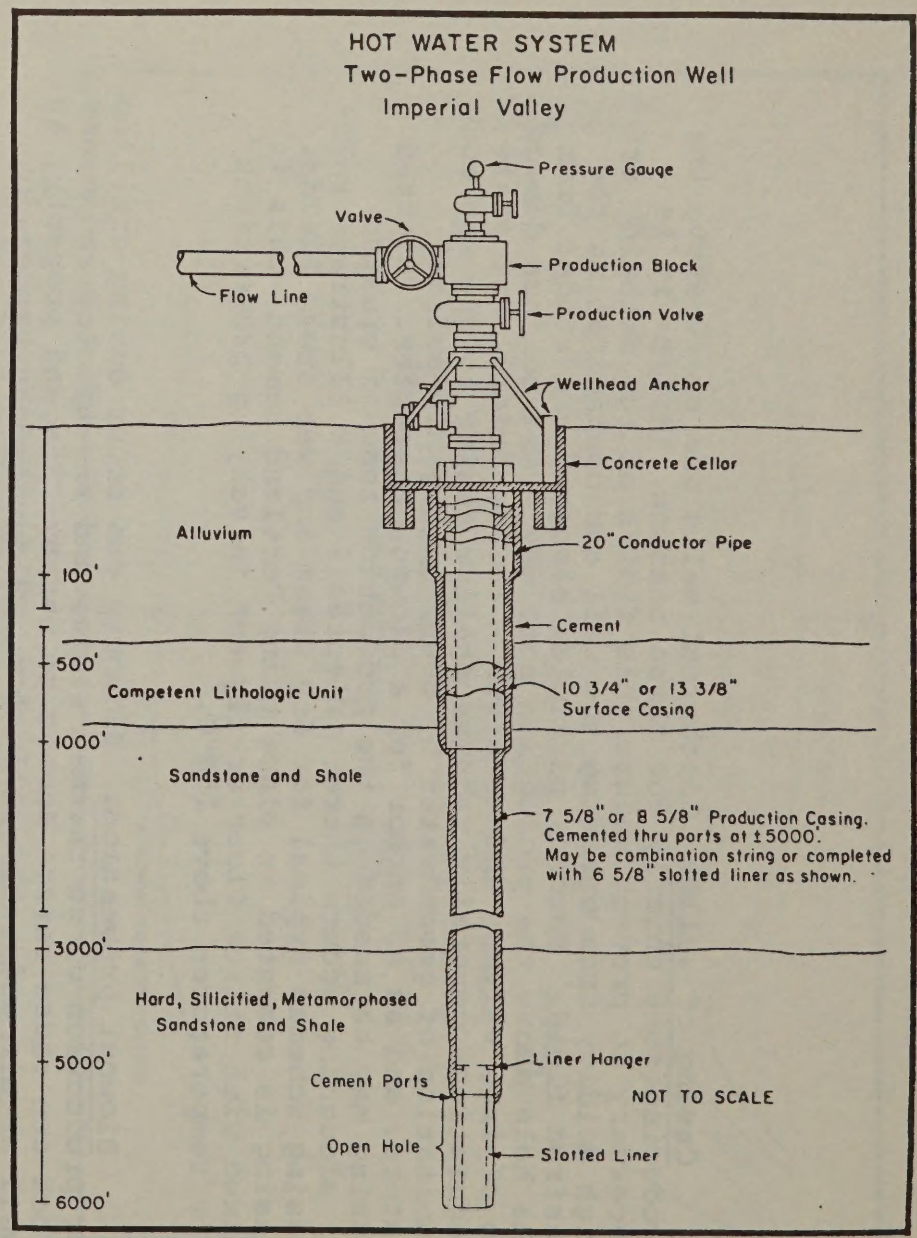


FIGURE 8 DIAGRAM FOR A TYPICAL CASING SCHEME FOR A PRODUCING WELL IN A TWO-PHASE (WET-STEAM) RESERVOIR (CAMPBELL, 1974, FIGURE 13)

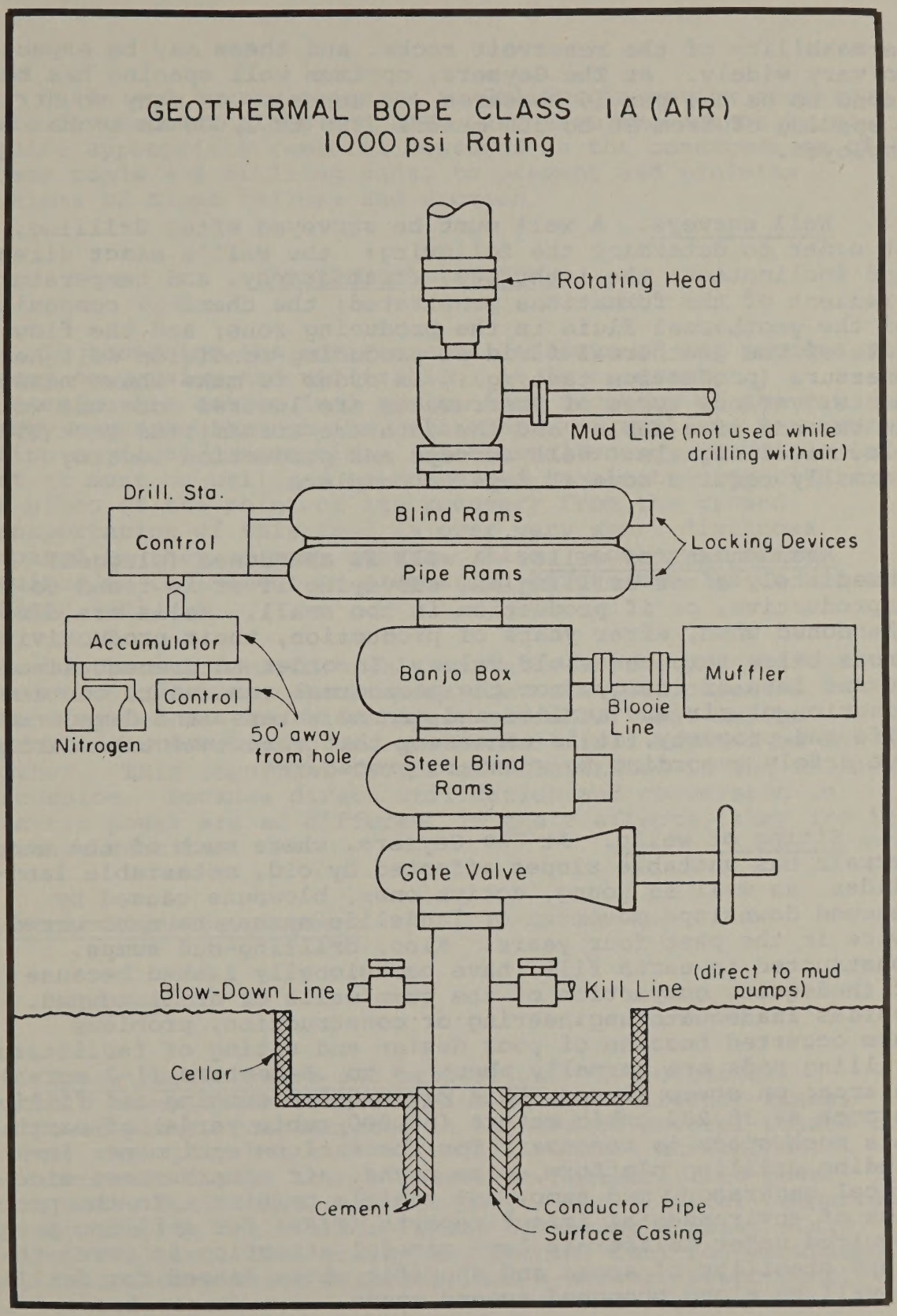


FIGURE 9 DIAGRAM OF TYPICAL BLOWOUT-PREVENTION EQUIPMENT USED IN AIR DRILLING (CAMPBELL, 1974, FIGURE 6)

permeability of the reservoir rocks, and these may be expected to vary widely. At The Geysers, optimum well spacing has been found to be one per 16 hectares (40 acres). In many countries, a spacing of from 90 to 300 meters (300 to 1,000 feet) has been employed.

Well surveys. A well must be surveyed after drilling, in order to determine the following: the well's exact direction and inclination; the lithology, stratigraphy, and temperature gradient of the formations penetrated; the chemical composition of the geothermal fluid in the producing zone; and the flow rate of the geothermal fluid at producing-condition well head pressure (production testing). In order to make these measurements, various types of instruments are lowered into the well at the end of a cable, and the data are transmitted back via electrical signals. Well surveys and production testing normally require several days to complete.

Abandonment of wells. A well is abandoned (plugged) immediately after drilling and surveying if it is found to be unproductive, or if production is too small. Wells are also abandoned when, after years of production, their productivity drops below some threshold value. In order to prevent damage to and loss of energy from the geothermal reservoir, contamination of air and surface and ground waters, and damage to life and property, it is necessary that abandonment be carried out safely according to standard procedures.

Siting of wells. At The Geysers, where much of the steep terrain has unstable slopes affected by old, metastable landslides, as well as young, active ones, blowouts caused by renewed downslope movement of landslide masses have occurred twice in the past four years. Also, drilling-mud sumps, constructed in earth fill, have occasionally leaked because of inadequate compaction of the sump walls or drilling pad. Besides inadequate engineering or construction, problems have occurred because of poor design and siting of facilities. Drilling pads are normally about .4 to .8 hectare (1-2 acres) in area; on steep slopes, this may require cutting and filling as much as 38,200 cubic meters (50,000 cubic yards) of earth. This much space is necessary for the various equipment, including drilling platform, pipe racks, air compressors, electrical generator, mud sump, and vehicle parking. In the preparation of environmental impact reports (EIRs) for drilling programs, required under California law, careful attention is given to the slope stability of areas and specific sites leased for drilling, as well as along proposed access roads.

State and county agencies in California review operators' field development plans and EIRs, and have the authority to require appropriate remedial measures in the construction of access roads and drilling pads, to prevent and minimize problems of slope failure and erosion.

Environmental Matters

In assessing the environmental effects of any process of energy conversion and utilization, it is necessary to examine the entire fuel cycle, from recovery of the raw energy resource through its refinement (if any) and transportation to final consumption. Geothermal energy is unique in that it must be utilized or converted to electricity within a few miles of the point of its recovery from the ground; transportation of this fuel is over very short distances compared to that of most others. Also, geothermal energy requires no refinement or processing before use, as do oil and nuclear fuel.

Geothermal fuel is highly variable in its physical and chemical properties, which means that the environmental effects attending its use are also highly variable: what may be a problem in developing one geothermal field may not be in another. This important factor is illustrated in the following discussion. Because direct utilization and conversion to electric power are so different in their effects, they are in separate sections.

Electric Power Development

Land use.

Space requirements and aesthetics. A geothermal electric power operation, with its wells, collector lines, and power plants concentrated in an area of several square kilometers, certainly has a more readily visible environmental and aesthetic impact than a fossil or nuclear fired power plant whose fuel comes from far away. For a fairer comparison, one may imagine the visible impact of having uranium strip mining, smelting, fuel enrichment plants, fuel-rod manufacturing, radioactive waste disposal, and a nuclear power plant, all located together.

In large-scale development (several hundred megawatts or more) or geothermal power, space is required for drilling pads of about .4 to .8 hectares (1 to 2 acres) each, and access roads to them, steam collector pipes, generating plants and transmission lines. With the present 16-hectare (40-acre) well-spacing at The Geysers, generation of 1,000 megawatts would require field development encompassing about 12 square miles. Approximately 20 percent of the total area, or from 2.6 to 5.2 square kilometers (1 to 2 square miles), would actually be used for siting of all facilities and roads.

In steep terrain, such as at The Geysers, geothermal development requires substantial modification of the landscape because excavation is necessary for construction of drilling pads, access roads, and power plants. In flatter terrain, however, little or no excavation is required.

Development of a geothermal field can be compatible with other land uses: at Lardarello, Italy, most land within the field is used for agriculture; at The Geysers, hunting and some cattle grazing continue much as they did before development. However, the production of geothermal resources can also cause changes in other forms of land use. In New Zealand the withdrawl of fluids has caused the subsidence of the land surface and the loss of hot springs and fumaroles, resulting in a shift in the local tourist industry. Discharge of waste hot water to local streams has caused a major change in the fisheries. In El Salvador, because of high boron content, fluid discharges to surface streams created a threat to irrigated crops downstream and a potential economic loss. On site, loss of wildlife habitat where natural vegetation is removed for road and facility construction is universally unavoidable.

New power transmission lines connecting the geothermal plant with existing lines must be constructed. Because these are very expensive, the proximity of existing lines is a factor, although a relatively minor one, in determining the commercial potential of a geothermal field. However it is conceivable that a geothermal field with a high capacity and long potential life would warrant the construction of up to 160 kilometers (100 miles) of new transmission line to connect the power plant with an existing power grid.

Erosion and Landslides. In steep terrain, increased erosion as a consequence of excavation can be a substantial problem during construction. Excavation of natural slopes tends to cause an increase in soil erosion, primarily because of over-steepening of cut-and-fill slopes and loss of vegetative cover, and also because of concentration of runoff on natural slopes. This causes an increase in stream siltation and suspended sediment load. When construction has ceased and soil cover has been re-established, erosion can be reduced. Appropriate precautions in grading - especially limits on maximum cut-and-fill slope angles and minimum compaction of fills - can reduce erosion.

Landsliding may be a serious engineering and environmental problem on steep slopes underlain by weak bedrock. At The Geysers, bedrock has been greatly weakened over broad areas due to hydrothermal alteration, faulting, and fracturing; numerous active and inactive (ancient, now metastable) landslides occur throughout the geothermal field. A California Division of Mines and Geology interpretation of a USGS geological reconnaissance stated that about 50 percent of the facilities at The Geysers are located on unstable slopes. A number of wells have been sited on ancient landslides, and one blowout may have been caused by renewed movement of a landslide. Excavation may trigger renewed movement of a landslide by disturbing natural drainage, and slopes cut in landslide masses are highly erodible. Although excavation of landslide material is now generally avoided or carefully controlled at The Geysers, early development there took little note of the problem.

Areas with gentle slopes generally have a reduced potential for accelerated erosion or landsliding as a result of construction. A large fraction of all known geothermal fields are beneath relatively flat terrain. Also, many fields that encompass both flat, low-lying terrain and steep upland areas will have to be drilled in their lower and flatter portions because depth to the reservoir would otherwise be too great for economic drilling. However, there will always be some increase in fluvial erosion from surface disturbance, and in certain areas wind erosion and an increased flash flood potential.

Land subsidence and earthquakes. Land subsidence and triggering of earthquakes are potential effects of geothermal development, chiefly in hot-water fields. In The Geysers and Lardarello fields, in production for 12 and 60 years, respectively, such effects have not been observed. It is theoretically most unlikely that subsidence could occur in

a dry-steam field, because the steam is greatly "underpressured" relative to normally-encountered hydrostatic pressures. Under such conditions, the reservoir rocks, not the geothermal steam, are already bearing essentially all of the overburden weight, and steam withdrawal should not cause subsidence. Actually, subsidence may have already occurred long ago, when the steam reservoir came into existence. As for seismic triggering, this is empirically always associated with an increase in fluid pore pressure in rocks. This has been observed in water-injected oil fields, fluid disposal wells near Denver, and in laboratory experiments. Steam withdrawal and partial reinjection reduces pore pressure, therefore earthquakes should not be triggered in a dry-steam field.

A hot-water field, however, is a different matter, because it is "overpressured," meaning that the water provides support of the overburden. Here, unless pressures are maintained by reinjection, subsidence may occur. Indeed, this has happened at Wairaki, New Zealand, where the water is not reinjected. Subsidence could be a serious problem in the Imperial Valley because extensive irrigation systems there could be easily disrupted by slight slope changes due to subsidence. Although total reinjection is contemplated for geothermal operations there, the cooling of geothermal hot water before reinjection could lead to significant decline in reservoir pressure, causing subsidence.

Triggering of earthquakes has not been observed in any hot-water field, and this is reasonable because pore pressures must decline as fluids are withdrawn, even with reinjection. Seismic effects may be possible by virtue of a redistribution of fluid pressure in a hot-water reservoir, and the fact is that geothermal fields are often located within seismically active areas, and along active faults. For this reason it is important that baseline seismic data be collected in seismically active geothermal areas, such as in the Imperial Valley prior to development, and the U. S. Geological Survey and California Institute of Technology have begun such work there.

Emissions. Fluid (liquid, vapor, and gas), thermal, and noise emissions attend the development and operation of a geothermal-electric generating system. Emissions during field development (well-drilling and facility construction) are distinctly different from those produced during operation. These two types of activity generally overlap for many years, from successful completion of a few producing wells to ultimate maximum field development.

Liquid emissions in drilling. In drilling any geothermal reservoir highly mineralized waters are often encountered. It is important that these not be dispersed into the environment, where they might do harm. Appropriate drilling procedures can prevent undesirable effects.

Contamination of shallow groundwater aquifers is a potential problem, but proper casing of the drill hole will prevent undesired fluids from a deep aquifer from entering a shallow one. In drilling with mud, it is necessary to store the mud and drill cuttings in a sump constructed in earth fill. Final disposal of this waste may be either in place, by evaporation of water and filling, or by removal to a designated disposal site. At The Geysers, the latter method is required by the County of Sonoma. In drilling with air, the cuttings are deposited in a sump. Mud sump leakage has been an occasional problem, but is easily prevented by proper design and location and adequate grading methods.

Liquid emissions in operation. The amount of geothermal steam or hot water required to generate a unit of electrical energy is a function of its enthalpy. In a dry-steam field (highest enthalpy) steam consumption is minimal (about 20 lbs/kwhr at The Geysers). Approximately 80% of this steam is evaporated in cooling towers, and the remaining 20% is condensed and reinjected into the reservoir.

The great majority of geothermal-electric plants are, and will probably continue to be, of the flashed steam type utilizing moderate to high-enthalpy hot water. Hot water consumption in such plants normally ranges from 75 to 150 lbs/kwhr. Thus a 100 mW plant would consume some 7-1/2 to 15 million lbs/hr, or 32-64 million cubic meters (26,000 to 52,000 acre-feet) per year of hot water. About 80% of this fluid remains as hot water after flashing and must be disposed of; as in a dry steam plant, about 20% of the steam must be condensed. Thus, about 84% of all produced fluid must be disposed of, either by reinjection, or on land, or both.

The binary cycle would use somewhat less geothermal fluid per kwhr than the flashed steam method. A range of 60 to 100 lbs/kwhr would result in a requirement of 26-43 million cubic meters (21,000-35,000 acre-feet) of geothermal fluid to drive a 100 mW plant. In this binary cycle system, all produced geothermal fluids are reinjected for engineering reasons of thermal efficiency and system maintenance. However, imported cooling water would be required and may amount to 12 million cubic meters (10,000 acre-feet) annually for a 100 mW plant in an arid climate.

These figures show readily that the flash steam process involves the greatest rate of fluid disposal per unit energy. High temperature geothermal waters used in flashed steam operations generally contain abundant dissolved minerals, which are concentrated by the process of flashing. Therefore they cannot usually be dumped into surface waters or shallow groundwaters without doing harm.

Chief chemical constituents of geothermal fluids are Na, Ca, K, Mg, Cl, HCO_3, SO_4 and SiO_4 in varying quantities. Geothermal steam at The Geysers has almost none of these, but has significant associated gases. Many hot water fields average between 2,000 and 20,000 ppm total dissolved solids (TDS), principally Na, Ca and Cl with varying amounts of the other constituents. Lesser but significant amount of Li, B, F and NO_2 may also be found. At Niland, Imperial Valley, TDS of 250,000 ppm or even higher is reported, again principally Na, Ca, K and Cl. Various heavy metals, such as iron, manganese, copper, lead, zinc and strontium also are found at Niland in concentrations ranging from a few tens to several hundred ppm. A few ppm of Fe, Mn, Al, As and other metals and metalloids may also be present in high temperature hot water fields. Dissolved gases may include O_2, CO_2 and H_2S, CH_4, H_2, NH_3 and N_2.

Because of industrial proprietary information rights, chemical analyses are generally unavailable for reservoirs in the western United States that have been drilled but not developed. However, it is expected that most if not all of these fluids, if produced, will have to be reinjected on account of their mineral content. At The Geysers, the power plant condensate contains significant boron and hydrogen sulfide, which would be harmful to vegetation if not reinjected. In the Imperial Valley, geothermal fluids are highly saline (from 15,000 to 250,000 ppm) and would have to be reinjected for that reason alone.

Gas and vapor. In air-drilling a dry-steam well, a "controlled blow-out" of steam is inevitable. After completion, the well must be allowed to blow out dust and rocks accumulated during drilling. This causes some unavoidable pollution of air by dust, steam, and gases for one to several days.

At The Geysers, the noncondensable gases produced from the wells form about 1 percent of the steam, of which about 80 percent is CO_2 with some CH_4, H_2, HN_4 and H_2S. Of these, H_2S is the most serious environmental contaminant, averaging 4.5 percent of the noncondensable gases and 225 ppm of the steam. About 30 percent of this is reinjected with the condensate, and the remainder (24+ tons/day) is released into the air.

Although this is considerably less sulphur than would be released from many fossil fuel plants of the same size, considerable pressure is being exerted to reduce H_2S emissions, because of odor.

Geothermal generating plants (dry or flashed steam) emit a great deal of water vapor from the cooling towers. A 1,000-mW complex would evaporate some 113,600 to 132,600 cubic meters (30-35 million gallons) of water per day. This could have a significant impact on local climate, depending on rate of mixing and dispersal of the vapor.

Thermal. From the laws of thermodynamics, the maximum thermal efficiency (i.e., percentage of heat converted to useful work) of any electrical generating plant now technically feasible is about 40 percent. Efficiencies of various types of power plants are as follows: fossil fuel, 36-40 percent; nuclear 32-34 percent; geothermal dry steam, 14-16 percent; geothermal flashed steam, about 3 percent. Geothermal generating plants yield a greater amount of waste heat per unit of electrical energy produced than do fossil or nuclear fueled plants because the temperature and pressure (hence the enthalpy) of natural steam is much lower than that of steam produced in a boiler.

Like all other thermal electric generating plants (fossil fuel and nuclear) geothermal power plants produce large amounts of hot waste water. However, unlike other plants, geothermal plants (with the exception of binary systems) produce enough water to provide a cooling loop without using external water supplies. It is also possible for geothermal plants to reinject waste hot water into the geothermal reservoir, making surface disposal unnecessary. The binary cycle requires a separate source of cooling water, and could cause thermal pollution.

Noise. Because of particular drilling techniques used in dry steam development, noise can formulate a significant environmental effect, though noise impact on wildlife is relatively unknown. In drilling, cleaning, testing, and bleeding (while on standby) wells, the steam must be allowed to escape through a blooie line. Except for bleeding, which may go on for years before hook-up to the power plant, these activities are quite brief, requiring not more than three months together for completion. At The Geysers, the use of mufflers has significantly reduced noise from these operations. In flashed steam or binary cycle development, noise will be less.

Direct Utilization

Direct uses of geothermal energy generally employ lower temperature, lower enthalpy, and shallower geothermal waters than those used in electric power generation. Cooler, shallower waters are generally less mineralized, and the volume rate of fluid produced is likely to be much smaller in direct use than in power generation. The total environmental impact of direct utilization will therefore probably remain small relative to power generation.

Except for space heating, greenhousing, and balneology, actual experience with direct utilization is very limited, and it is difficult to predict the environmental effects of future applications such as in industrial processing.

Land use. Space heating, greenhousing and balneology, the main direct uses, require only very small amounts of land for a few wells and collector lines. The visual and habitat impacts of these operations are negligible, except when located in areas of unusual character. Even if wells are in steep, unstable terrain, they are likely to be so few in number as to have a negligible impact on erosion. The small volume and shallow depth of produced fluids should cause very little or no subsidence, especially if they are reinjected.

Industrial process heating may require drilling of more and deeper wells. This would increase land use impacts somewhat, but they would probably be much smaller than in full-scale electric power development. However, if an industrial complex and community were built to make maximum use of a low-enthalpy reservoir, then primary (field development) and secondary (construction) impacts would be very substantial.

Emissions. At present, heat-depleted geothermal waters used in space heating, greenhousing, and soil warming are discharged directly into natural surface waters. In several places, geothermal waters are used directly for stock watering, and in Boise, Idaho, for domestic hot water. In Klamath Falls, Oregon, heat exchanging coils in wells are used to transfer heat from geothermal waters to domestic water prior to using the latter for heating; thus there are no mineral or gas emissions. Nevertheless, the effects of discharging some low-enthalpy geothermal waters into surface waters could be harmful, because some of these are heavily mineralized and may contain toxic elements such as arsenic and boron.

Industrial processes may utilize deeper geothermal waters of higher temperature and mineral content. Some of these probably could not be discharged into surface waters, but would have to be reinjectd.

Noise and gas emissions should not be significant primary impacts of low- to moderate-enthalpy geothermal water development. However, secondary impacts could be important.

Secondary Impacts

As in all cases of geothermal resource development, environmental impacts can occur through the slow accumulation of low-level pollutants in the bio-physical system, or through minor modifications in the physical system resulting in slow changes in the biological community. In addition, increased economic development may attend the development of geothermal resources and may impart environmental impacts which are not directly a result of geothermal development. These may be increased demand on local water supplies, domestic water pollution, and the replacement of animals and habitat by human settlement.

GLOSSARY

ACTIVE FAULT - A fault along which measurable displacement has occurred in comparatively recent geologic time (usually late Quaternary or Holocene).

ACTIVE SEISMIC METHOD - Uses explosives to produce acoustic waves which are reflected and refracted through the earth and recorded by arrays of sensitive pick-ups (geophones); geologic structure is inferred from the recorded signals.

ANDESITIC - Designates a volcanic rock of intermediate composition, i.e., moderately silicic.

ANOMALY - In geology, a local feature distinguishable in a geophysical, geochemical, or geobotanical measurement over a larger area; a feature considered capable of being associated with commercially valuable deposits.

BALNEOLOGY - The therapeutic use of natural mineral waters by bathing.

BASALTIC - Designates a volcanic rock low in silica, and rich in iron and magnesium; opposite of silicic.

BASIN AND RANGE PROVINCE - A large region characterized by tilted fault-block mountains separated by basins filled with young sediments.

BINARY CYCLE - In geothermal power-plant design, denotes the use of a heat exchanger to conduct heat from a geothermal brine to the working fluid (low-boiling point fluid such as isobutane) which drives a turbine.

BLOOIE LINE - A steam-well vent used to bleed off steam when the well is on standby (i.e., not in service).

BLOWOUT - The sudden, often explosive escape of steam and perhaps hot water from a geothermal well; may be caused by improper drilling procedures or rupture of casing and wellhead equipment.

BTU - British Thermal Unit; a unit of energy equal to .000298 kilowatt-hour.

CASING - The steel pipe used to line a drill hole.

CENOZOIC - The youngest major subdivision of geologic time, extending from the present to 65 million years before present.

COAST RANGE SUBDUCTION ZONE - The site of the oceanic trench in which the Coast Ranges of California were formed during the period from about 150 million to 30 million years ago, and where the North American overrode the Pacific tectonic plate.

COLORADO PLATEAU - The uplifted region of flat-lying sedimentary rocks in Utah, Colorado, Arizona, and New Mexico.

CONVECTION - A process of mass movement in a fluid medium (gas, liquid or plastic solid), in which cooler, denser material settles, and lighter, hotter material rises, causing vertical, near-circular flow. The process thus moves both the medium and the heat.

CORROSION - A process in which a solid (usually a metal) is eaten away by a fluid (usually an acid).

CRUST - The outermost layer of the earth, composed of relatively cool, brittle, low-density rocks (compared with the mantle), and ranging in thickness from 5 kilometers (beneath ocean floors) to 30 to 50 kilometers (under continents).

DIAGENESIS - Process involving physical and chemical changes in sediment after disposition that converts it to consolidated rock.

DIPOLE - In resistivity surveys, denotes two electrodes implanted in the ground which are used either to induce a current field in the earth (i.e., a current or transmitting dipole), or to measure voltage gradients produced by such current fields (i.e., a receiving dipole).

DIPOLE-DIPOLE - Denotes a type of resistivity survey in which transmitting and receiving dipoles are of the same length (i.e., electrodes spaced equivalently), and wherein the receiving-dipole stations are located at regular intervals along a line perpendicular to and bisecting the transmitting dipole.

DIRECT-CURRENT RESISTIVITY SURVEY - Uses a direct-current generator to produce an electric field in the earth, which is then measured with a voltmeter at many different points; many different electrode configurations (connections of generator and voltmeter to the ground) are employed; the resistivities of buried rock units can be inferred by calculation.

DRILLING RIG - Equipment used to drill through rock formations; shallow temperature-gradient holes are drilled with a truck-mounted rig; deep exploration holes are drilled with a large, stationary rig. (For details see section on drilling practice.)

DRILL STEM - Steel pipe used to turn the rotary drill bit and through which drilling fluid is circulated.

DRY STEAM - Steam without entrained liquid water, i.e., pure steam.

EAST PACIFIC RISE - A bathymetrically high axis extending in a northerly direction across the east Pacific Ocean; the axis of crustal spreading along the east edge of the Pacific plate.

ELECTROMAGNETIC SOUNDING - Uses a direct- or alternating-current generator to produce either a continuous electromagnetic wave or transient pulse, which is induced in buried conductive rock; this induced field is detected by a coil connected to a recorder, and the recorded signal is used to interpret the resistivities of subsurface rock units.

ENTHALPY - Heat content per unit mass, expressed in BTU/lb or cal/gm.

EXOTHERMIC - A chemical reaction releasing heat.

EXSOLUTION - Unmixing.

FAULT - A fracture or fracture zone along which two rock masses have been displaced relative to one another.

FLASHED STEAM - Steam produced by the boiling of superheated water upon release of confining pressure.

FLUVIAL - Produced by steam action.

FUMAROLE - A hole, vent, or geyser which emits steam or gaseous vapor; found usually in volcanic areas.

GEOCHEMICAL INDICATORS - In the geothermal context, geochemical anomalies indicating the presence of a potentially valuable geothermal prospect.

GEOCHEMISTRY - Chemistry of the earth; applied geochemistry uses chemical analyses to find economic resources, including minerals and geothermal fluids.

GEOPHYSICS - Physics of the earth; applied geophysics uses various methods of measuring physical characteristics of the earth's crust to locate economic resources.

GEOPRESSURE - Fluid pressure exceeding hydrostatic pressure.

GEOTHERMAL - Of or relating to the earth's natural heat.

GEOTHERMAL FLUX - The amount of earth heat moving radially outward per unit surface area per unit time, expressed as microcalories/cm^2/sec.

GEOTHERMAL GRADIENT - The rate of temperature increase with depth below the earth's surface, in °C/km or °F/100 feet.

GEOTHERMOMETER - A geochemical method which uses groundwater chemistry to estimate the temperature of a geothermal reservoir.

GRAVITY SURVEY - Uses a gravimeter to measure the strength of the earth's gravity field at many points in the survey area; these data are used to interpret density variations in the crust, and, from that, deep geologic structure.

GREYWACKE - An impure sandstone common in mountains that formed in subduction zones; a very prevalent rock in the Coast Ranges of California.

GROUND NOISE - See seismic noise.

HEAT FLOW - See geothermal flux.

HYDROLOGY - The study of ground and surface waters - their chemical and physical properties, location, flow, and geologic environment.

HYDROSTATIC PRESSURE - The pressure exerted at any given depth by a column of water rising from that depth to the earth's surface.

HYDROTHERMAL ALTERATION - Mineralogical changes in rocks caused by the addition or removal of materials through the action of hydrothermal fluids (gas or mineralized water of volcanic origin).

HYGROSCOPIC - The ability of a mineral (esp. montmorillonite) to absorb water which becomes bound within the crystal lattice; such bound water may be released only as steam, upon being heated to the boiling point.

IGNEOUS ROCK - Formed by crystallization of molten rock (called magma) within the earth (granites) or at the surface (volcanic rock).

IMPERMEABLE - Not permeable (see permeable).

INTRUSION - The process of injection of magma into the shallower portion of the earth's crust; an igneous rock body formed by this process.

KELLY - A removable collar, which transmits the rotary motion of the rotary table to the drill stem, and supports the drill stem.

KGRA - (Known Geothermal Resources Area) - An area which the Mineral Land Classification Committee of the United States Geological Survey has designated as potentially valuable for production of geothermal energy; KGRAs are essentially confined to public-domain lands (under BLM administration), and their establishment is based on both scientific and competitive-interest criteria.

KILOWATT-HOUR (kwhr) - The energy represented by one kilowatt of power consumed for a period of one hour; equals 3,415 BTU; in the U. S., the installed generating capacity supplies approximately 1 kwhr of energy per person per hour.

LAND SUBSIDENCE - The sinking of land, usually due to withdrawal of natural underground fluids (oil or water) by man.

LITHOLOGY - The physical character of a rock.

LOST CIRCULATION (ZONE) - Refers to the loss of drilling mud which occurs when the drill bit penetrates a particularly porous and permeable zone (often created by open fractures or a rubbly lava-flow); a zone characterized by lost circulation.

MAGMA - Molten rock.

MAGNETIC SURVEY - Uses a magnetometer (either airborne or on the ground) to measure the intensity of the earth's natural magnetic field at many points in the survey area; the data are then used to interpret geologic structure.

MAGNETOTELLURIC SOUNDING - Relies on the earth's natural electrical (telluric) and magnetic fields which are induced in subsurface conductive rocks; the resistivity of buried conductive rock units can be inferred from measurements of these fields at the earth's surface.

MAGNITUDE - (Richter-scale magnitude) in seismology, denotes the size of an earthquake according to the logarithm of its amplitude as recorded on a seismogram (seismograph record).

MANTLE - The spherical shell of the earth's interior, lying beneath the crust and above the core; it is about 2,900 kilometers (1,800 miles) thick, hot, plastic.

MEGAWATT - One thousand kilowatts.

METASTABLE - Marked by only a slight margin of stability.

METEORIC WATER - Rainwater entering soil or rock and percolating downward.

MICROEARTHQUAKE - A small earthquake, with Richter magnitude less than 3, and which is normally not felt.

MID-OCEAN RIDGE - A chain of volcanic mountains in the ocean, under which magma rises, erupts, and cools, adding new crustal material to the margins of two separating tectonic plates.

MONTMORILLONITE - A group of hygroscopic clay minerals.

MUD SUMP - A pit, usually constructed in earth fill, for storage of drilling mud and drill cuttings.

Na-K-Ca GEOTHERMOMETER - A method of calculating the temperature of a geothermal reservoir from the relative concentrations of Na (sodium), K (potassium), and Ca (calcium) present in a geothermal fluid sample; it is based upon empirical data on the equilibrium solubilities of those ions as a function of temperature.

NATURAL FIELD - In geophysics, denotes any naturally occurring potential field, i.e., electrical, magnetic, electromagnetic, or gravitational.

NORTH AMERICAN PLATE - The tectonic plate encompassing all of North America and Atlantic Ocean west of the mid-Atlantic Ridge.

OCEANIC RISE - Like a mid-ocean ridge, but with lower relief.

PACIFIC PLATE - The tectonic plate encompassing all of the North Pacific, and most of the South Pacific ocean.

PASSIVE SEISMIC METHOD - An exploration technique relying on naturally occurring seismic waves (e.g. from earthquakes).

PERMEABLE - A solid through which a fluid can move.

POVE - A space in rock or soil not occupied by solid mineral matter.

ppm - Parts per million, by weight.

PROSPECT - An area in which the presence of an economic resource is indicated.

RECONNAISSANCE - The initial investigation of a large area in order to locate prospects or targets.

REINJECTION - The injection of produced geothermal fluids back into the reservoir from which they came through disposal wells.

RESERVOIR - A space in which a fluid is stored.

RESISTIVITY - Electrical resistance per unit length in any material; this varies widely with rock type, porosity, temperature and salinity.

RIFTING - The process of rift formation, in which crustal plates pull apart, forming tensional faults.

RIFT ZONE - A broad fault zone along which tectonic plates pull apart from each other.

ROTARY DRILL RIG (STATIONARY) - A very large piece of equipment, including a drilling platform and mast (or derrick) which together may stand about 30 meters (100 feet) high. The diesel engine used to turn the drill stem is beneath the platform, and the mast above is used to handle and feed-in sections of drill stem as the hole is deepened. A drill bit is attached to the bottom of the drill-string (sections of drill stem).

SALINITY - A measure of the TDS of water; for comparison, sea water has TDS of about 30,000 ppm.

SCALING - Precipitation and deposition of dissolved solids in pipes or other containers (of geothermal or other fluids).

SCHLUMBERGER - In electrical resistivity surveying, denotes a collinear array of transmitting and receiving dipoles having a particular electrode-spacing relationship.

SEDIMENT - In geology, rock and mineral debris which has been eroded, transported, and deposited by wind, water, or ice (glaciers).

SEDIMENTARY - A rock composed of sediments, usually deposited in water.

SEISMICITY - Earthquake activity.

SEISMIC NOISE - Ambient or background seismic energy which can by measured anywhere on the earth's surface; its characteristics vary with local geologic structure.

SILICA GEOTHERMOMETER - A method of calculating the temperature of a geothermal reservoir from the concentration of SiO_2 in a geothermal fluid sample; it is based upon empirical data on the equilibrium solubilities of quartz and calcedony as a function of temperature.

SILICIC - Applied to igneous rock containing 66 percent or more of silica, such as rhyolite, dacite, granite and quartz monzonite.

SINTER - A mineral deposit formed by a mineral spring, either hot or cold; typically either silica or calcium carbonate.

SLOUGH (-ed, -ing) - A term used to describe the breaking loose of rock fragments from the sides of a drill hole.

SPACE HEATING - Heating of air inside a building.

SPREADING CENTER - An axis along which hot, plastic rock of the upper mantle rises and spreads out; may be a mid-ocean rise or ridge, or beneath a continental rift zone.

STRATIGRAPHY - The description of the sequence of stratified rocks; particularly concerned with the age relations of sedimentary formations.

SUBDUCTION ZONE - A zone of mountain building, usually at the edge of a continent, where one tectonic plate slips beneath another and is consumed (re-melted) at depth along a sloping fault zone; much of the circum-Pacific tectonic belt is a subduction zone.

TARGET - See prospect.

TDS - Total dissolved solids.

TECTONIC - Refers to those processes by which rocks of the crust and upper mantle are deformed (faulted, fractured, folded).

TECTONIC PLATE - A large area of the crust and upper mantle (shallower than about 100 kilometers or 60 miles) that moves or is rafted across the underlying mantle as a unit over a long period of geologic time; the process of shifting is called continental drift.

TELLURIC - (See magnetotelluric).

TEMPERATURE-GRADIENT SURVEY - Uses a probe to sample temperature at successive points in a drill hole, in order to determine the rate of temperature increase with depth.

TENSIONAL FAULTING - Faulting produced by tension in the earth's crust, and resulting in extension thereof.

TRAVERTINE - Calcium carbonate deposited from solution in ground and surface waters, and frequently found around springs.

VAPOR-DOMINATED RESERVOIR - One in which dry steam predominates over hot water.

VOLCANISM - Natural processes resulting in the formation, movement, eruption, and crystallization of magmas, forming volcanoes and volcanic rocks.

WASATCH FRONT - The topographic and geologic boundary between the Basin and Range province on the west, and the Colorado Plateau and Rocky Mountains on the east.

WELL-LOG - A record of the lithology or certain geophysical properties of rocks penetrated by a well.

WENNER - In electrical resistivity surveying, denotes a collinear array of transmitting and receiving dipoles having a particular electrode-spacing relationship.

Part II - Current Status of Geothermal Leasing and Exploration

Five activity categories are defined here, and the areas subject to these activities are shown on separate maps. There are crude estimates of the total acreage likely to experience some degree of reconnaissance-level exploration (casual use), and still cruder estimates of acreage subject to detailed exploration, including drilling of shallow temperature gradient holes and/or deep exploratory tests. An attempt has been made to show areas in which deep drilling is likely from 1975-1977.

Known Geothermal Resource Areas are an administrative classification of the U. S. Department of the Interior, by means of which acreage believed to have higher-than-average potential for discovery of geothermal resources is offered for competitive lease, requiring a bonus bid. These areas are established by administrative decree, and have arbitrarily-defined boundaries. As a result, KGRAs sometimes have little relationship to the actual geothermal resource, and usually are far more extensive than the resource area in nature. Many KGRAs are the scene of intensive exploratory interest; others have attracted no attention from industry, either because of restrictions on land use or because of better exploratory data. KGRAs are shown on the various state maps, and are listed in the text with names of companies which have purchased leases on acreage from the Department of the Interior.

A more detailed "Development Guide" follows the maps and discusses present status and future likelihood of exploration at some two dozen target areas. Also included is a table for inter-relating costs of exploration with stages of geothermal exploration and development, as well as with sizes of areas involved.

On each state map, irregular circles are keyed to the degree of anticipated exploration. Since exploration is unpredictable and often secretive, circles are imprecise. As exploration has progressed, interest has been lost in some KGRAs, which are therefore not circled. Such shifts in exploration will continue and it is therefore futile to try to closely identify federal acreage within a circle. Information is based on data available in December 1975 and should be updated annually.

The letters A, M and L are added to each target area to indicate abundant federal acreage (estimated over 50 percent), moderate federal acreage (estimated 10 to 50 percent), and little federal land (estimated less than 10 percent). Most areas are classified as A, except for The Geysers region, Imperial Valley, and certain other settled, often irrigated valleys, such as around Chandler, Arizona or Steamboat Springs, Nevada. Therefore, if exploration does proceed at almost any of the targeted areas, some impact will be felt on public lands.

KEY FOR THE FOLLOWING MAPS

1 Producing field

2 Drilling underway - significant discoveries - development perhaps by 1980

3 Drilling anticipated in 1976-1977

4 Significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 Past drilling - no activity known at present

(A) Abundant federal land in and around the area

(M) Moderate federal land in and around the area

(L) Little federal land in and around the area

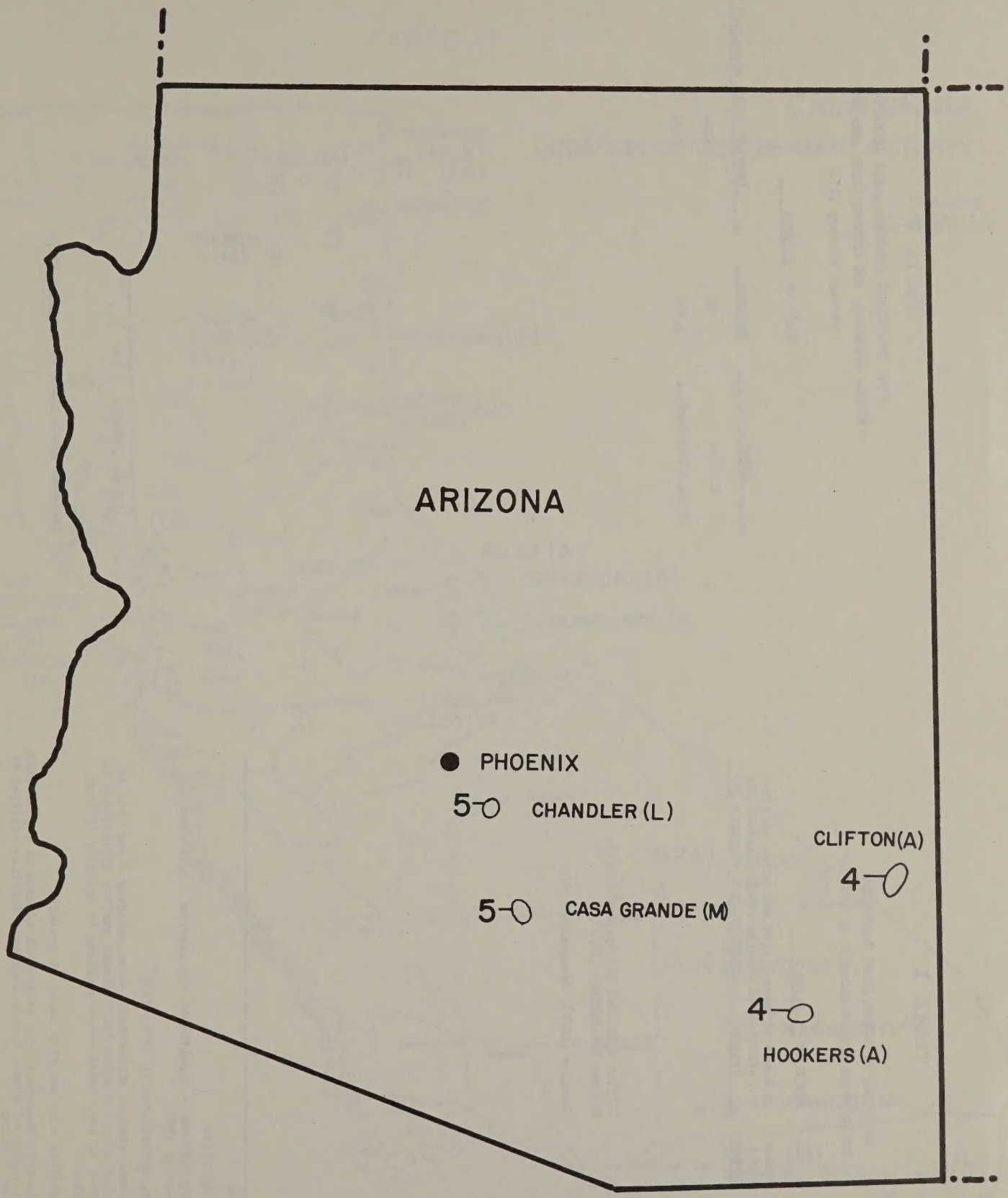


FIGURE 10
LOCATION OF GEOTHERMAL ACTIVITY

Table 1

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF ARIZONA

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	0	
3	0	
4	2	Clifton & Gillard Hot Springs (30/5), Hookers Hot Springs (20/2)
5	2	Chandler (10/2), Casagrande (10/0)

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years.

Table 2

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

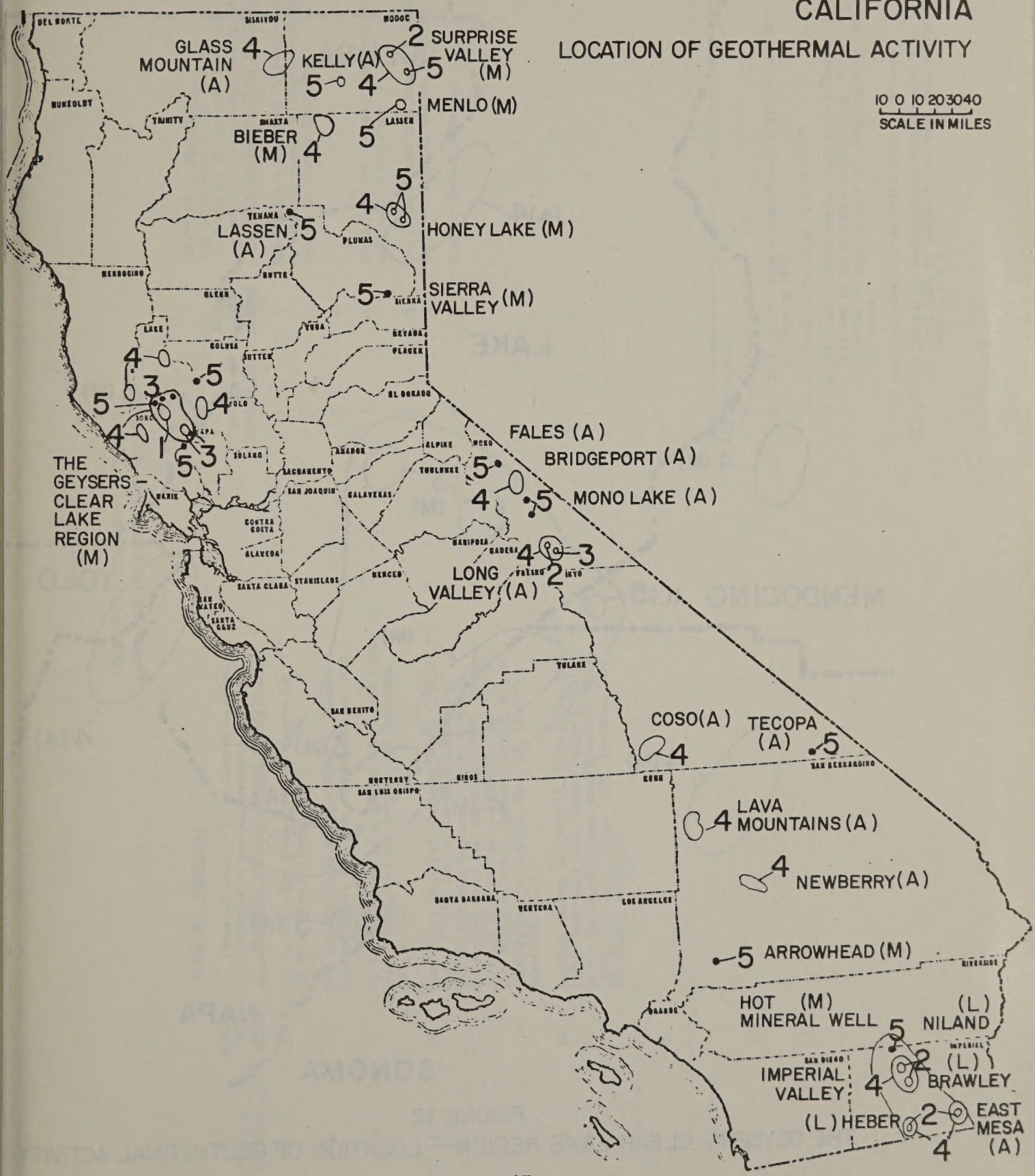
STATE OF ARIZONA

KGRA*	Acreage	Lessees (with acreages)
Clifton	780	none
Gillard Hot Springs	2,920	none

TOTAL ACREAGE: 3,700

* includes areas added to original KGRA

FIGURE 11


CALIFORNIA
LOCATION OF GEOTHERMAL ACTIVITY
10 0 10 20 30 40
SCALE IN MILES
GLASS MOUNTAIN (A)
KELLY (A)
SURPRISE VALLEY (M)
MENLO (M)
BIEBER (M)
HONEY LAKE (M)
LASSEN (A)
SIERRA VALLEY (M)
THE GEYSERS - CLEAR LAKE REGION (M)
FALES (A)
BRIDGEPORT (A)
MONO LAKE (A)
LONG VALLEY (A)
COSO (A)
TECOPA (A)
LAVA MOUNTAINS (A)
NEWBERRY (A)
ARROWHEAD (M)
HOT MINERAL WELL (M)
NILAND (L)
IMPERIAL VALLEY
BRAWLEY (L)
HEBER (L)
EAST MESA (A)

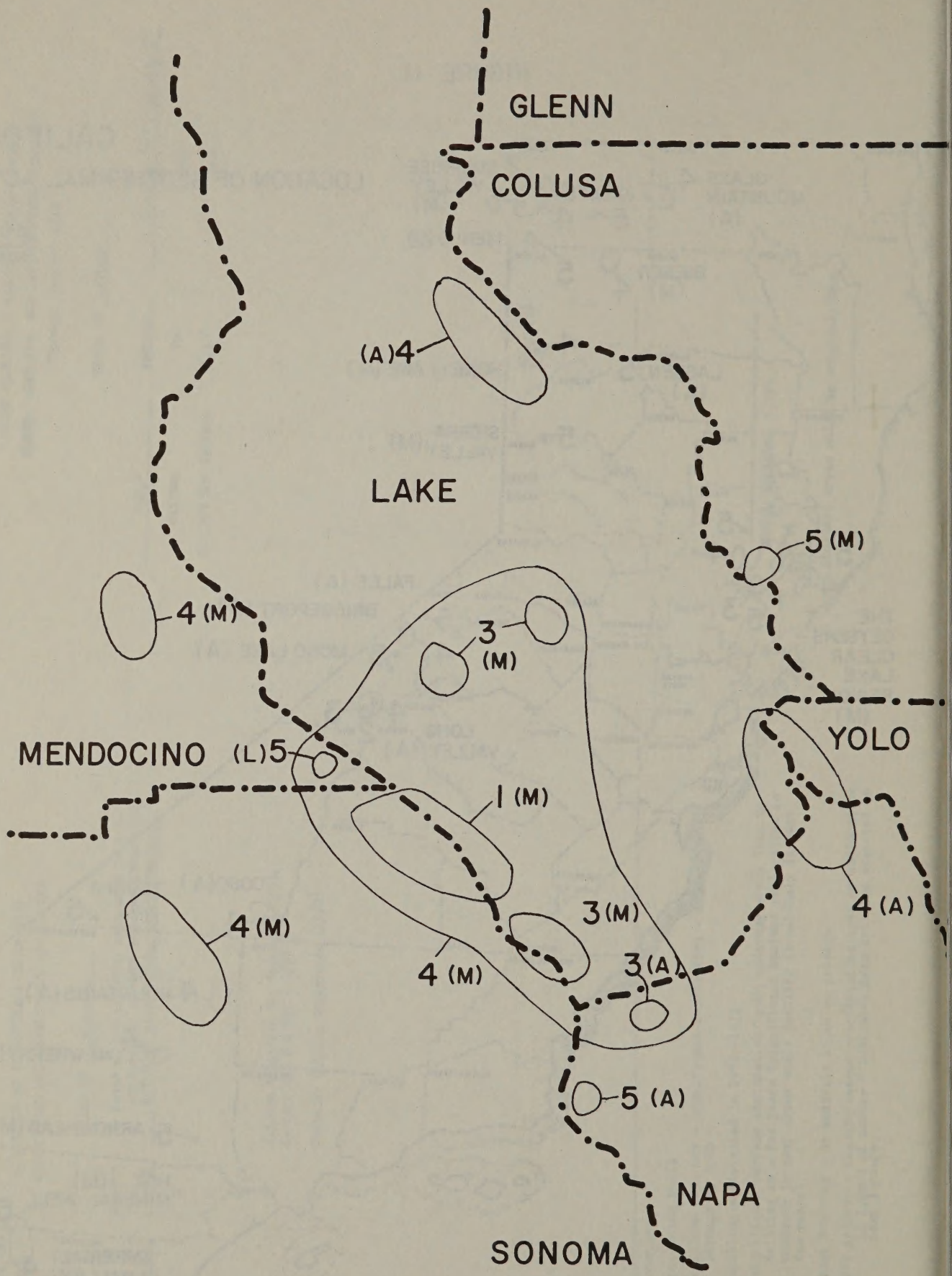


FIGURE 12
THE GEYSERS-CLEAR LAKE REGION — LOCATION OF GEOTHERMAL ACTIVITY

Table 3

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF CALIFORNIA

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	1	The Geysers - dry steam field now generating 500 Mw of electric power
2	6	Lake City (Surprise Valley); Mammoth, Niland, Brawley, Heber, East Mesa - high-enthalpy brine
3	5	Mt. Konocti, Borax Lake, Mayacmas Mountains southwest of Middletown and northeast of Calistoga, Lake Crowley
4	19	Glass Mountain (40/5), Surprise Valley (30/15*), Bieber (20/2), Susanville (10/2), Honey Lake (20/5), Bartlett, Hopland, Skaggs, Knoxville, The Geysers-Clear Lake Region (150/30*), Bridgeport (25/5), Long Valley (50/20*), Coso (25/5*), Lava Mountain (25/10), Newberry (15/2), Niland (30/5*), Brawley (15/5*), East Mesa (20/2*), Heber (20/10*)
5	14	Surprise Valley, Kelly (5/0), Menlo (5/0), Lassen (3/0), Honey Lake area, Sierra Valley (10/0), Wilbur Spring, Calistoga, near Glenbrook, Fales (1/0), Mono Lake, Tecopa (3/0), Arrowhead (2/0), Hot Mineral Well (5/0)

STATE OF CALIFORNIA
THE GEYSERS-CLEAR LAKE REGION

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	1	The Geysers - dry steam field now producing 500 Mw electric power - ultimate development may produce as much as 2,000 Mw.
2	0	
3	4	Borax Lake, Mt. Konocti, southwest of Middletown, northeast of Calistoga
4	5	The Geysers-Clear Lake Region (150/30*) Bartlett, Hopland, Skaggs, Knoxville
5	2	near Glenbrook, Calistoga

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 4

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF CALIFORNIA

KGRA*	Acreage*	Lessees (with acreages)
Glass Mountain	33,287	none
Lake City-Surprise Valley	72,252	Getty (3,000 ±)
Lassen	78,641	none
Wendell-Amedee	17,292	none
Beckworth Peak	2,560	none
Love Lady Ridge	6,879	none
Witter Springs	18,152	none
Little Horse Mountain	1,196	none
The Geysers-Calistoga	374,910	Shell Oil (3,874), Union Oil (3,448), Burmah Oil (876), Occidental Pet. (382)
Knoxville	14,702	none
Bodie	640	none
Mono-Long Valley		Geothermal Resources International (3,710), Republic Geothermal (1,773)
Coso Hot Springs	51,760	none
Saline Valley	3,200	none
Randsburg	12,880	none
Sespe Hot Springs	7,034	none
Ford (Dry) Lake	7,687	none
TOTAL ACREAGE:		

STATE OF CALIFORNIA

KGRA*	Acreage*	Lessees (with acreages)
Salton Sea	95,824	
Brawley	28,885	
Dunes	7,680	
East Mesa	38,365	Magma Power Co. (5,065), Republic Geothermal (6,705)
Glamis	25,505	
Heber	58,568	
TOTAL ACREAGE:	1,418,319	

* includes areas added to original KGRA

FIGURE 13

COLORADO

LOCATION OF GEOTHERMAL ACTIVITY

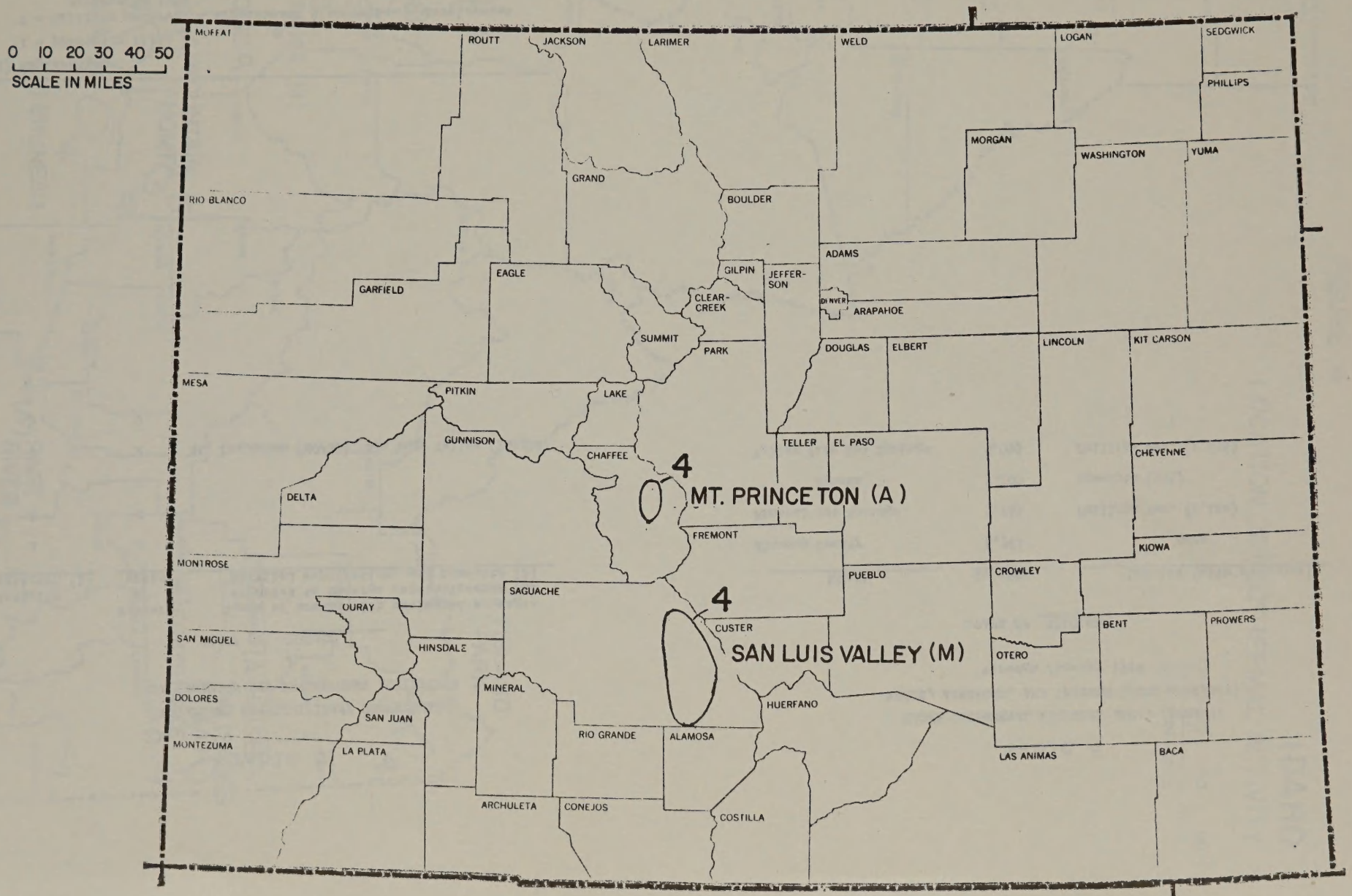


Table 5

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF COLORADO

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	0	
3	0	
4	2	Mt. Princeton (40/10), San Luis Valley (100/20)
5	0	

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 6

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF COLORADO

KGRA*	Acreage	Lessees (with acreages)
Alamosa County	6,761	none
Mineral Hot Springs	5,765	Phillips Pet. (2,484)
Poncha	3,200	Anschutz (915)
Valley View Hot Springs	5,099	Phillips Pet. (1,636)

TOTAL ACREAGE: 20,825

* includes areas added to original KGRA

FIGURE 14

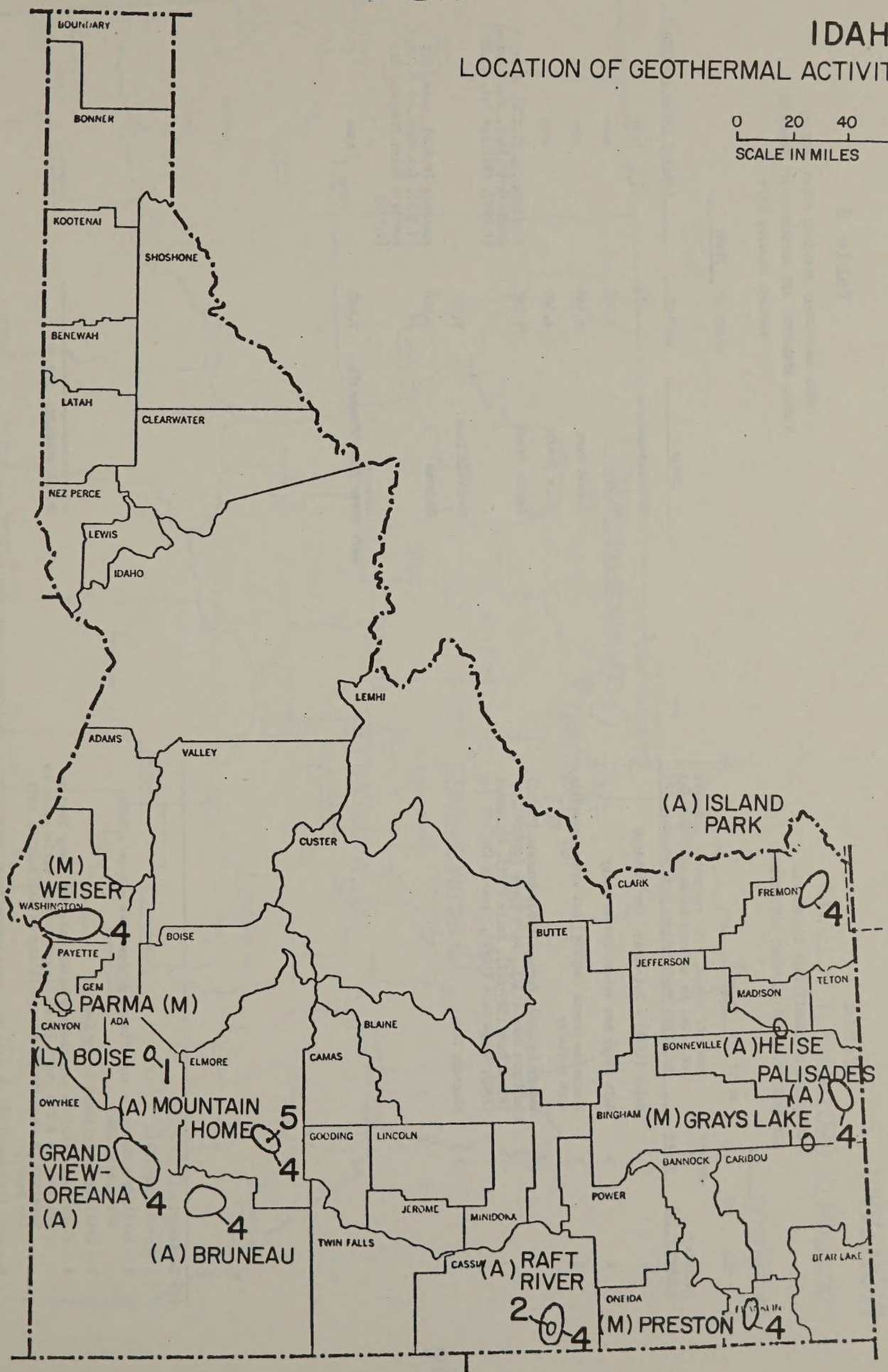

IDAHO
LOCATION OF GEOTHERMAL ACTIVITY
0 20 40 60
SCALE IN MILES
BOUNDARY
BONNER
KOOTENAI
SHOSHONE
BENEWAH
LATAH
CLEARWATER
NEZ PERCE
LEWIS
IDAHO
LEMHI
ADAMS
VALLEY
CUSTER
(M) WEISER
WASHINGTON
4
PAYETTE
BOISE
GEM
PARMA (M)
CANYON
ADA
(L) BOISE
1
ELMORE
OWYHEE
(A) MOUNTAIN HOME
5
4
GRAND VIEW-OREANA (A)
4
4
(A) BRUNEAU
BLAINE
CAMAS
GOODING
LINCOLN
JEROME
MINIDOKA
TWIN FALLS
CASSIA
(A) RAFT RIVER
2
4
BUTTE
CLARK
(A) ISLAND PARK
FREMONT
4
JEFFERSON
MADISON
TETON
BONNEVILLE
(A) HEISE PALISADES
(A)
4
BINGHAM
(M) GRAYS LAKE
4
BANNOCK
CARIBOU
POWER
ONEIDA
(M) PRESTON
4
BEAR LAKE

Table 7

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF IDAHO

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	1	Boise (1/1*) - hot water, low enthalpy
2	1	Raft River hot water, low enthalpy
3	1	Grandview-Oreana (80/20*) hot water, possibly high enthalpy
4	10	Weiser (50/8*), Parma (10/0), Bruneau (70/10), Mountain Home (15/3), Raft River (40/10*), Island Park (100+/10), Heise (5/1), Palisades (2/0), Grays Lake (10/2), Preston (10/2*)
5	1	Mountain Home

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 8

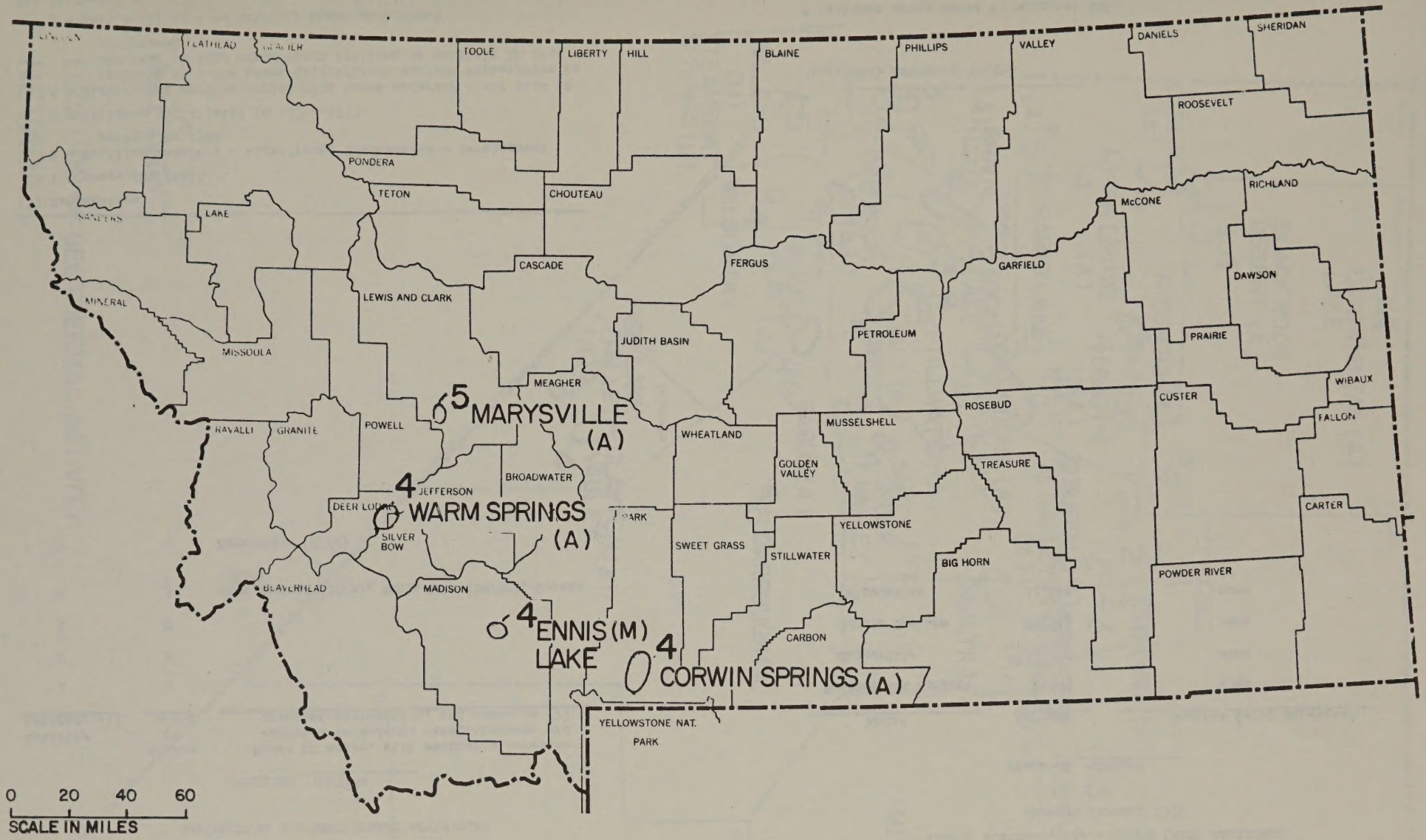
KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF IDAHO

KGRA*	Acreage	Lessees (with acreages)
Yellowstone	14,164	none
Vulcan	3,836	none
Island Park	28,539	none
Crane Creek	4,342	none
Castle Creek	79,722	Anschutz Co. (1,720), Nancy P. Anschutz (7,184), Dow Chemical (2,080), Phillips Pet. (5,025)
Mountain Home	9,520	
Bruneau	5,120	Anschutz (2,600), Getty Oil (5,913), Dow Chemical (2,083), Southern Union Products Co. (2,586)
Raft River (was "Frazier")	7,680	none

TOTAL ACREAGE: 152,923

* includes areas added to original KGRA



LOCATION OF GEOTHERMAL ACTIVITY

MONTANA

FIGURE 15

Table 9

LOCATIONS OF SIGNIFICANT GEOTHERMAL EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF MONTANA

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	0	
3	0	
4	3	Warm Springs (30/5), Ennis Lake (20/5*), Corwin (40/0)
5	1	Marysville (20/2)

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 10

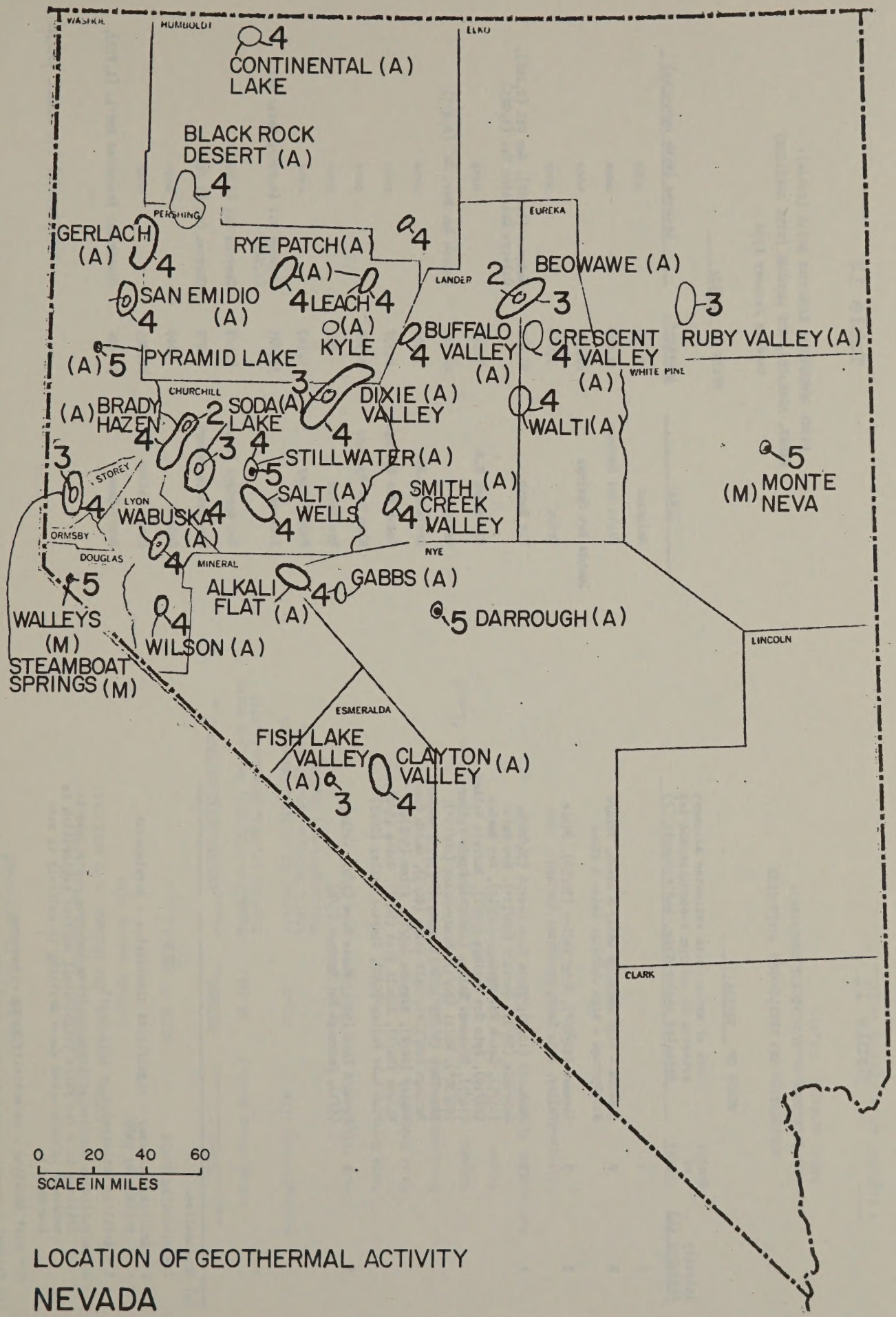
KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs): NAMES, ACREAGES, AND LESSEES (WITH ACREAGES) through January 1976

STATE OF MONTANA

KGRA*	Acreage	Lessees (with acreages)
Boulder Hot Springs	6,343	none
Marysville	19,200	none
Corwin Springs	20,349	none
Yellowstone	14,164	none

TOTAL ACREAGE: 60,056

* includes areas added to original KGRA



LOCATION OF GEOTHERMAL ACTIVITY

NEVADA

FIGURE 16

Table 11

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF NEVADA

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	2	Beowawe - high enthalpy water & steam, Bradys Hot Springs - high enthalpy water & steam
3	5	Beowawe (40/20*), Ruby Valley (30/5*), Dixie Valley, Soda Lake, Steamboat Springs
4	25	Baltazor (10/0), Black Rock Desert (70/20*), Golconda (10/3), Gerlach (40/15*), Rye Patch (15/5), Leach Hot Springs (10/10), San Emidio (20/10), Kyle Hot Springs (10/2), Buffalo Valley (10/5), Crescent Valley (40/20*), Dixie Valley (80/30*), Walti (20/5), Brady-Hazen (40/10*), Soda Lake (50/25*), Stillwater (20/5), Steamboat Springs (40/10*), Salt Wells (40/5), Smith Creek Valley (10/2), Wabuska (15/2), Allen (5/1), Wilson (10/5), Alkali Flat (20/2), Gabbs (5/0), Fish Lake Valley (5/0), Clayton Valley (20/3)
5	4	Pyramid Lake (5/0), Monte Neva (2/0), Walleys (5/1), Darrough Hot Springs (5/0)

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 12

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF NEVADA

KGRA*	Acreage*	Lessees (with acreages)
Baltazor	5,537	none
Pinto Hot Springs	8,065	none
Double Hot Springs	29,326	none
Trego	7,013	none
Fly Ranch	20,662	Natomas (1,467), Sun Oil (2,161), Calvert Drilling Co. (3,023)
Fly Ranch N.E.	7,971	none
Gerlach	26,326	Sunoco En. Dev. Co. (8,493)
Gerlach N.E.	7,971	none
Leach Hot Springs	8,957	none
Elko Hot Springs	8,960	none
Rye Patch	801	none
Ruby Valley	5,743	none
Beowawe	33,225	Chevron Oil (6,890), Getty Oil (4,940)
Hot Springs Point	8,549	Chevron Oil (4,701)
San Emidio Desert	7,678	Chevron Oil (1,612)
Colado	640	none
Dixie Valley	38,989	none
Brady-Hazen	98,446	Geothermal Resources Int'l. (1,772),

continued on next page

Table 12 Continued

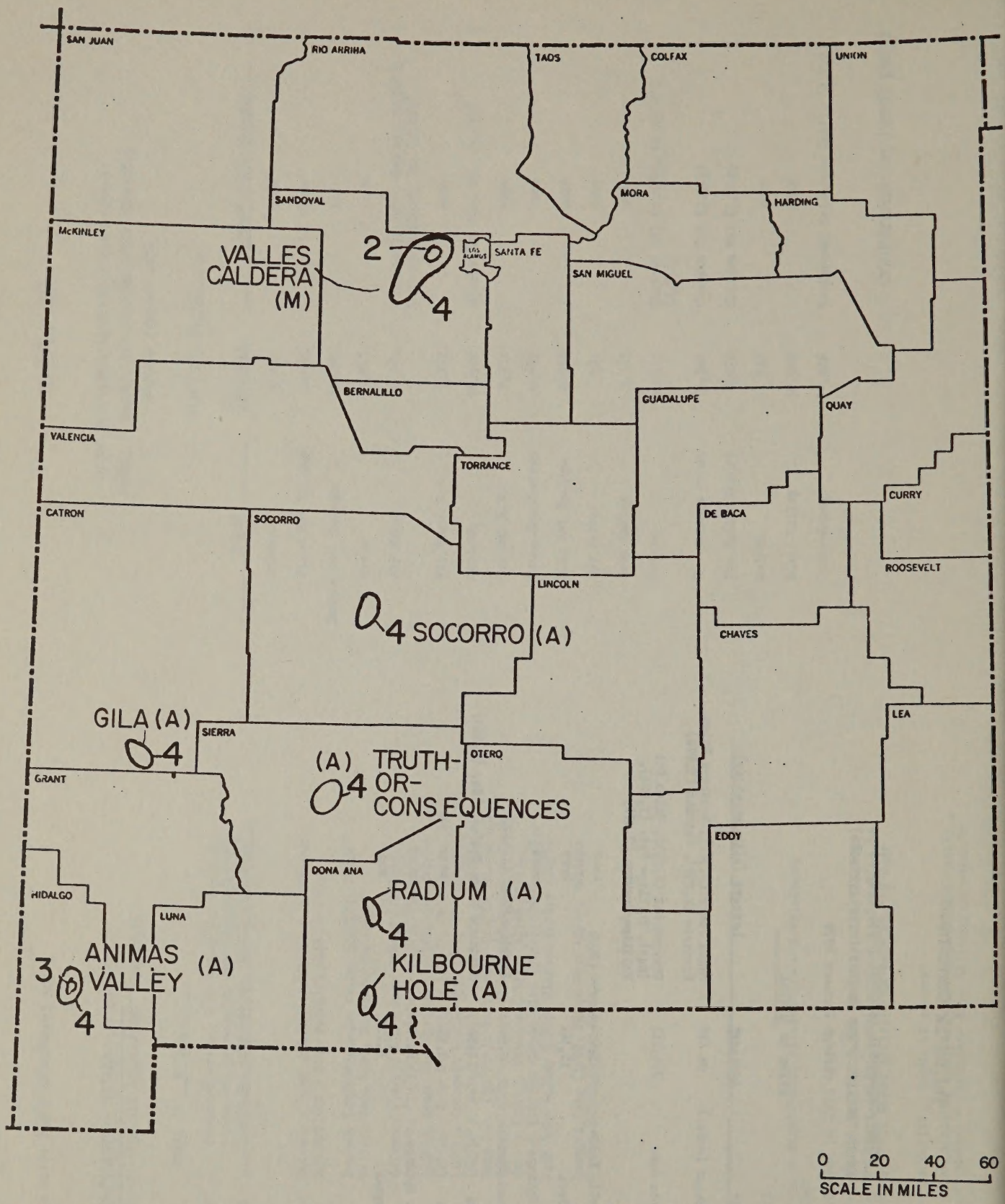
KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF NEVADA

KGRA*	Acreage*	Lessees (with acreages)
Brady-Hazen (cont.)	98,446	Magma Power (2,561), Southern Union Products (2,402), Natomas (5,074)
Stillwater-Soda Lake	225,211	Chevron Oil (2,319), Union Oil (843), Phillips Pet. (7,624), Phillips/Chevron (2,472)
Salt Wells Basin	19,232	none
Monte Neva	10,302	none
Moana Springs	5,120	none
Steamboat Springs	8,914	Phillips/Gulf (1,547)
Wabuska	11,520	Southern Union Products Co. (5,640)
Wilson	1,294	none
Darrough Hot Springs	8,398	none
Silverpeak	5,117	none

TOTAL ACREAGE: 611,935

* includes areas added to original KGRA



LOCATION OF GEOTHERMAL ACTIVITY

NEW MEXICO

FIGURE 17

Table 13

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF NEW MEXICO

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	1	Valles Caldera - wet steam
3	1	Cotton City
4	6	Valles Caldera (60/40*), Socorro (15/2), Gila Hot Springs (25/2), Truth-or-Consequences (30/5), Radium Springs (10/2), Animas Valley (40/20*)
5	0	

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 14

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF NEW MEXICO

KGRA*	Acreage	Lessees (with acreages)
Baca Location No. 1	168,761	none
San Ysidro	1,915	none
Lower Frisco Hot Springs	5,760	none
Gila Hot Springs	3,202	none
Radium Springs	9,813	none
Kilbourne Hole	25,134	Anadarko Oil (18,476)

TOTAL ACREAGE: 214,585

* includes areas added to original KGRA

OREGON

FIGURE 18

LOCATION OF GEOTHERMAL ACTIVITY

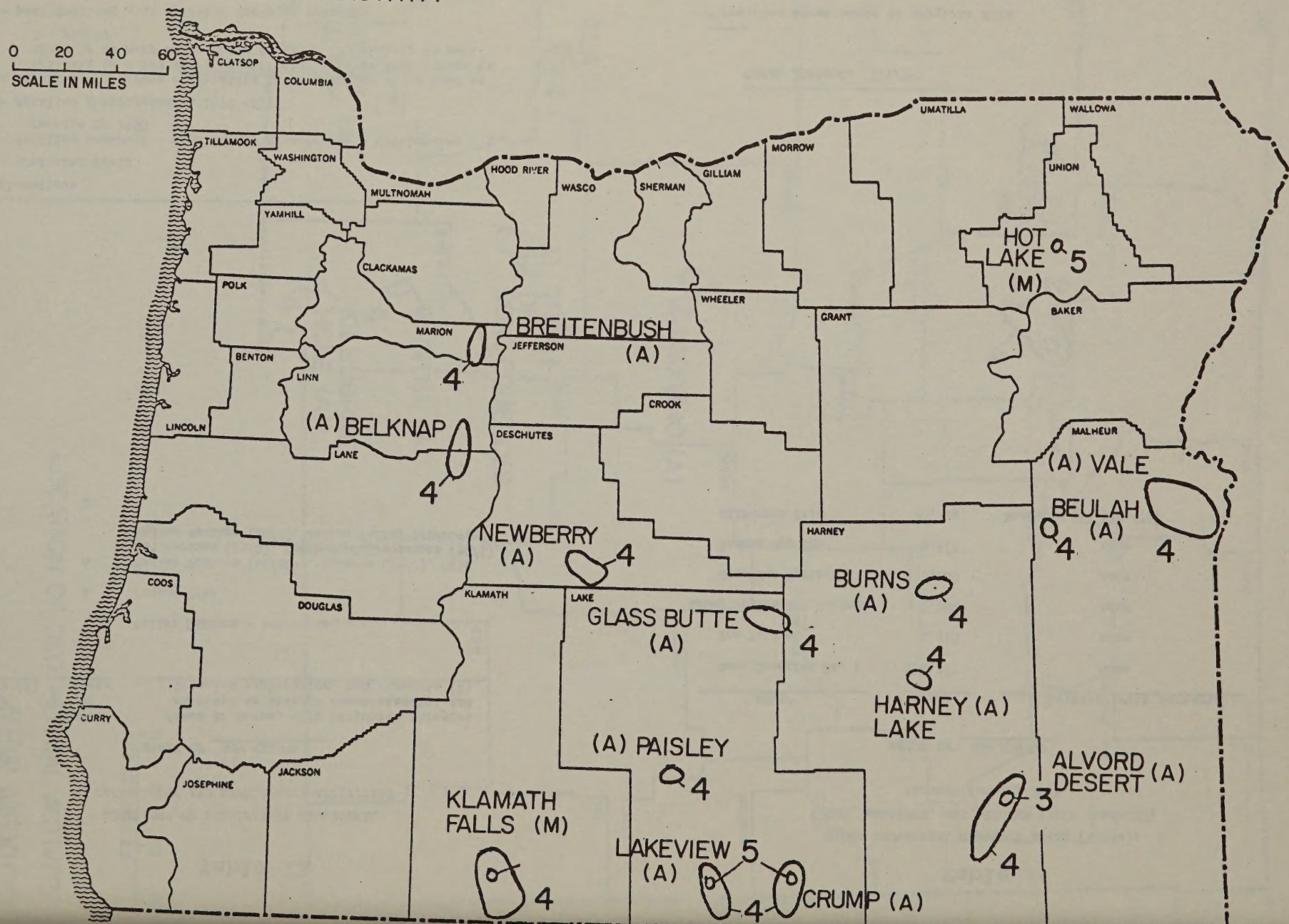


Table 15

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF OREGON

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	1	Klamath Falls - low-enthalpy hot water
2	0	
3	1	in Alvord KGRA
4	13	Breitenbush (30/2), Belknap (50/10), Vale (80/25*), Beulah (15/2), Burns (20/2), Glass Butte (40/5), Newberry (30/0), Harney Lake (15/2), Alvord Desert (40/20*), Paisley (20/5), Klamath Falls (70/15*), Lakeview (30/10), Crump Geyser (45/10*)
5	3	Hot Lake (20/1), Lakeview, Crump Geyser

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 16

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF OREGON

KGRA*	Acreage	Lessees (with acreages)
Mount Hood	8,671	none
Carey Hot Springs	7,579	none
Breitenbush Hot Springs	13,445	none
Belknap-Foley Hot Springs	5,066	none
McCredie Hot Springs	3,659	none
Burns Butte	640	none
Vale Hot Springs	22,998	Union Oil (4,486), Geothermal Resources Int'l. (2,560), Republic Geothermal (1,347)
Summer Lake Hot Springs	13,631	none
Alvord	176,835	Al Aquitaine Pet. (7,520), Southern Union Products (2,560), Republic Geothermal (10,082), Chevron Oil (2,560), Mapco (6,331), Getty Oil (2,126)
Klamath Falls	50,300	
Lakeview	12,165	
Crump Geyser	85,663	Chevron Oil (9,463)

TOTAL ACREAGE: 367,652

* includes areas added to original KGRA

FIGURE 19

UTAH

LOCATION OF GEOTHERMAL ACTIVITY

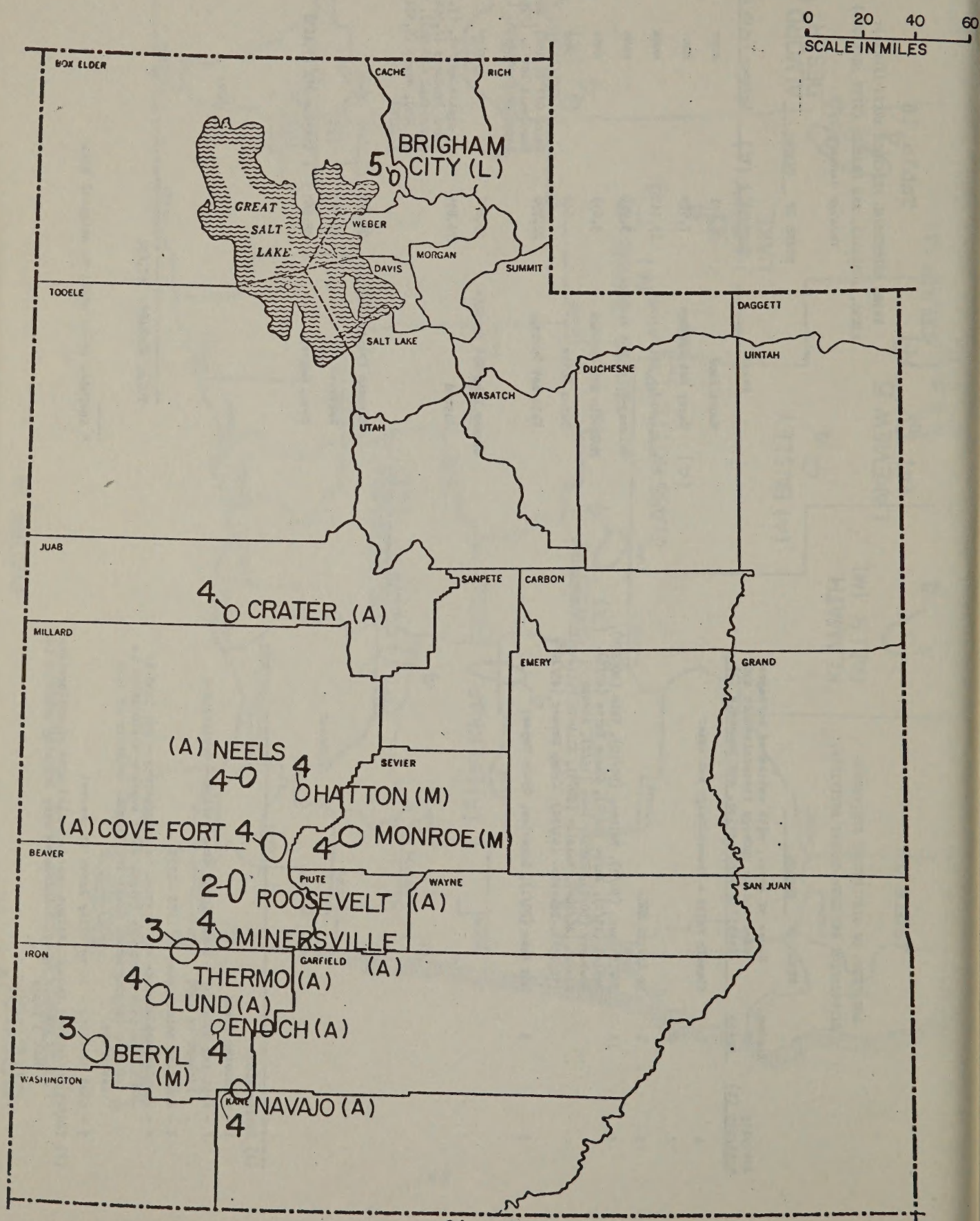


Table 17

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF UTAH

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	1	Roosevelt Hot Springs (25/20*) - hot water
3	3	Cove Fort - Sulphurdale (25/20*), Thermo (35/15*), Beryl (40/10*): drilling at Beryl now; Cove Fort & Thermo likely
4	8	Crater Springs (10/5), Neels (10/0), Hatton (5/3), Monroe-Joseph (10/5), Minersville (5/2), Lund (15/5*), Enoch (10/5), Navajo Lake (10/0)
5	1	Brigham City

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 18

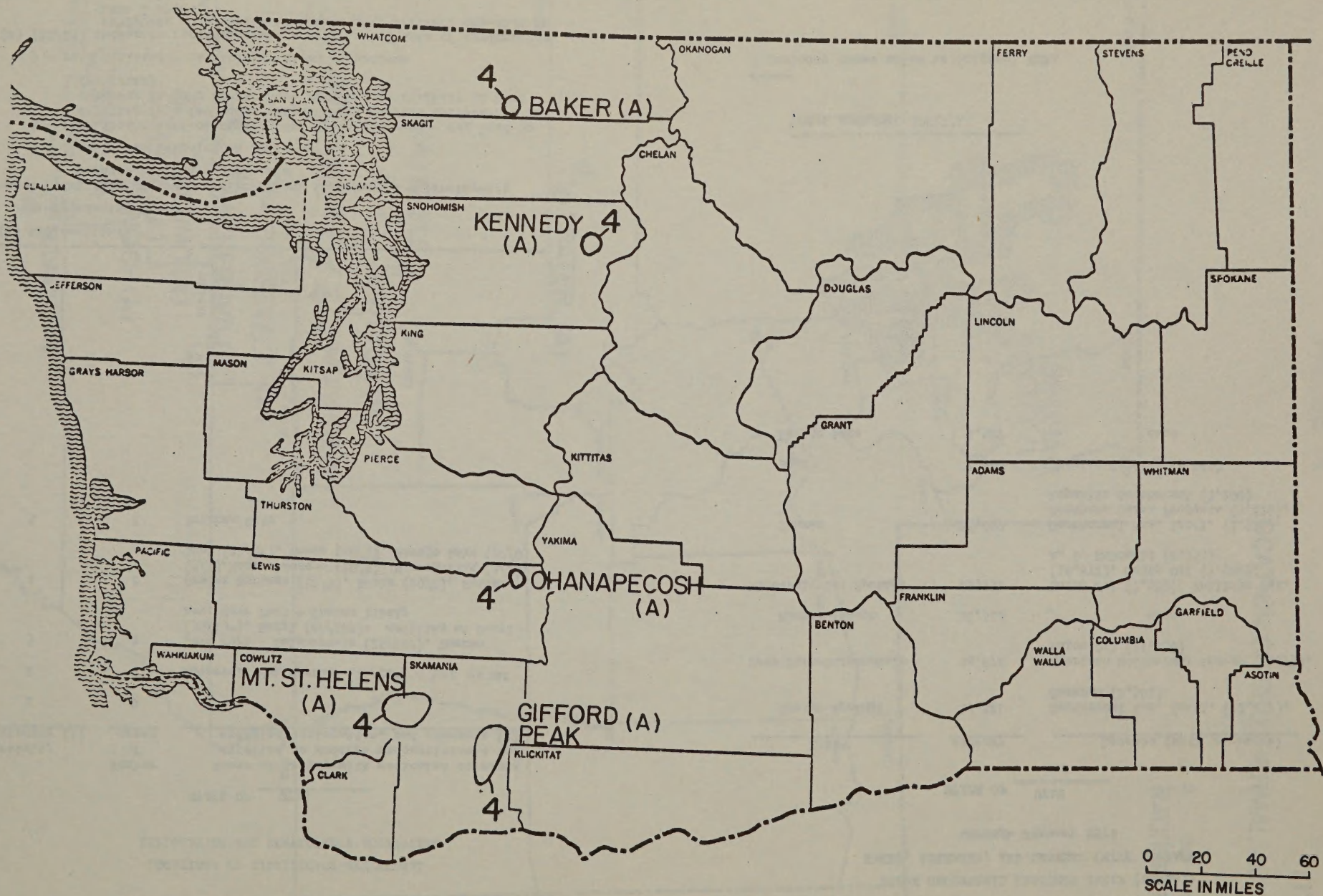
KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF UTAH

KGRA*	Acreage	Lessees (with acreages)
Crater Springs	17,321	Geothermal Res. Int'l. (12,417), Chevron (2,582)
Cove Fort-Sulphurdale	24,874	American Geothermal Energy (7,579), Union Oil (11,830)
Monroe-Joseph	16,364	none
Roosevelt Hot Springs	29,791	Union Oil (2,560), Phillips Pet. (18,872), Getty Oil (1,920), A. L. McDonald (2,335)
Thermo	26,019	Geothermal Res. Int'l. (1,920), Southern Union Products (5,476), Republic Geothermal (1,200)
Lund	3,840	Charles Golding (3,360)
Navajo Lake	2,522	none

TOTAL ACREAGE: 120,731

* includes areas added to original KGRA



LOCATION OF GEOTHERMAL ACTIVITY

WASHINGTON

FIGURE 20

Table 19

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF WASHINGTON

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	0	
3	0	
4	5	Mt. Baker (10/0), Kennedy Hot Spring (10/2), Ohanapecosh (5/0), Mt. St. Helens (60/5), Gifford Peak (35/3)
5	0	

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 20

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF WASHINGTON

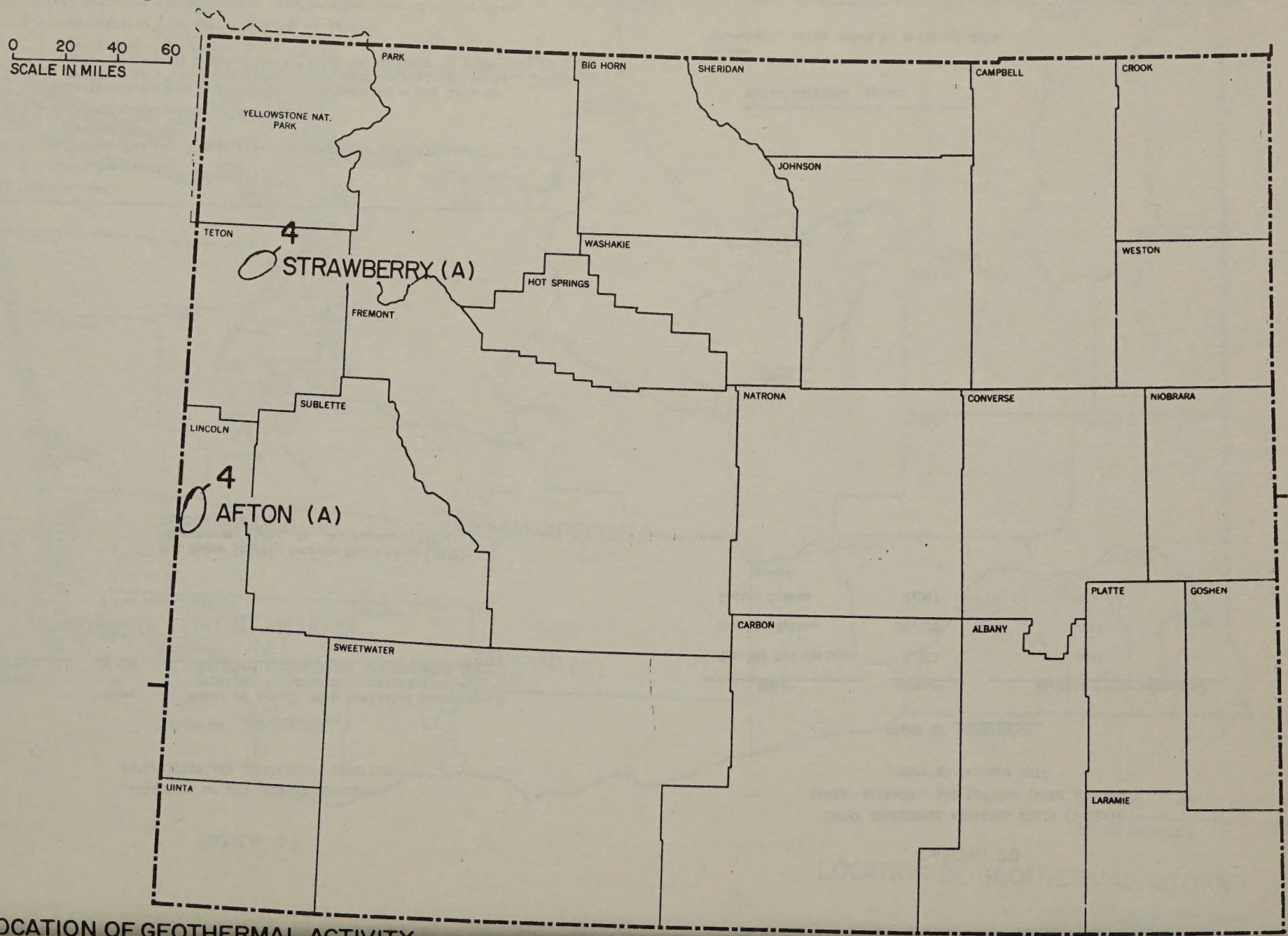
KGRA*	Acreage	Lessees (with acreages)
Kennedy Hot Springs	3,311	none
Mt. St. Helens	29,755	none
Indian Heaven	2,547	none

TOTAL ACREAGE: 35,613

* includes areas added to original KGRA

WYOMING

FIGURE 21



LOCATION OF GEOTHERMAL ACTIVITY

Table 21

LOCATIONS OF SIGNIFICANT GEOTHERMAL
EXPLORATION AND DEVELOPMENT ACTIVITIES

STATE OF WYOMING

Activity category (1)	Number of areas	Names of areas, with estimated acreages expected to undergo reconnaissance and detailed exploration, and comments (2)
1	0	
2	0	
3	0	
4	2	Strawberry (10/0), Afton (30/5)
5	0	

(1) Explanation:

1 - producing field

2 - drilling underway - significant discoveries - development perhaps by 1980

3 - drilling anticipated in 1976 -1977

4 - significant surface exploration known underway - may lead to drilling in a few years (significant surface exploration is underway in many areas where drilling is unlikely in next few years)

5 - past drilling - no activity known at present

(2) (10/2*) indicates reconnaissance area/detailed area of exploration, in 1,000s of acres; * indicates deep drilling expected in next 3 years

Table 22

KNOWN GEOTHERMAL RESOURCE AREAS (KGRAs):
NAMES, ACREAGES, AND LESSEES (WITH ACREAGES)
through January 1976

STATE OF WYOMING

KGRA*	Acreage	Lessees (with acreages)
NONE		

TOTAL ACREAGE:

* includes areas added to original KGRA

Table 23

FORECAST GUIDE FOR THE MOST ACTIVE GEOTHERMAL DEVELOPMENT AREAS

Area	Development State	Forecast 1975-1976	1977-1979	1980-1985
		Dry Steam (Vapor Dominated)		
The Geysers, CA	500 mW of plant installed by PG&E in 11 units; over 150 holes drilled across 18 mi^2, of which 2 in 3 encounter steam; most of remainder are hot but non-productive; wells drilled by Union Oil, Thermal Power, Pacific Energy Company, Burmah Oil, Shell Oil, Sun Oil and others.	To average about 20 holes drilled per year (Union Oil, Shell Oil, Pacific Energy, Burmah Oil, others); step-out drilling to SE and N; occasional redrilling of existing wells.	Units #12-15 to be installed (400 mW); step-out drilling to N, NW, possibly NE and SE, covering additional 10 to 15 mi^2; continued redrilling within productive area.	Development to exceed 1500 mW; probably the field limits and dimensions will be known; may exceed 25-30 mi^2 (2500 mW capacity) in area.
		High Enthalpy (>200-250 BTU/lb) Hot Water (324-550°F)		
Valles Caldera, NM	Approximately 9 producible wells, of about 15 holes drilled in 10 mi^2 area (Union Oil); negotiations with utility over contract to sell steam.	Continued drilling of development wells and testing of field; possible agreement to construct 50 mW flashed-steam power plant.	Drilling of wildcat holes by other operators; construction of first plant; continued development drilling.	Further construction of plant facilities; definition of field dimensions; continued drilling and testing.
Imperial Valley, CA	4 areas being tested for development. Heber: 9 holes across 3 mi^2; lower enthalpy hot water; Chevron, Magma Power. Brawley: 3 holes in limited area; lower enthalpy water; Union. Niland: 15 holes in 10 mi^2; high enthalpy, heavy brine; Phillips, Magma Power, Southern Pacific Co. East Mesa: 4 holes in limited area; lower enthalpy hot water; USBR.	Continued testing of heat-exchanging for Niland brine; further drilling in other areas; testing of heat-exchanging components for binary cycle power generation; testing of desalination apparatus at East Mesa.	Construction of first binary-cycle plant at Heber (20 mW); continued drilling at Heber and Brawley; possible decision to construct pilot desalination facility at East Mesa; possible decision to construct power plant at Brawley and/or Niland; wildcat drilling elsewhere.	Development at Heber continuing; possible continued activity elsewhere.
Roosevelt, UT	Approximately 4 holes drilled in limited area (Phillips Petroleum); testing and further drilling underway.	Continuing testing and drilling; possible wildcat drilling in adjoining areas (Cove Fort to northeast).	Possible decision to construct power plant; if so, further drilling.	Possible construction of plant, with continuing drilling and testing of wells.
Carson Desert, NV	4 areas have been drilled to varying degree. Brady's: about 12 holes, across 2 mi^2 area; Union, Magma Power. Soda Lake: 2 holes, widely spaced; Chevron, Phillips. Fernley: 2 holes; Magma Power. Stillwater: 1 hole; O'Neill-Olliphant.	Continuing drilling and testing (Brady's and Soda Lake); possible wildcat drilling in adjoining areas.	Possible decision to construct power plant at undecided site; if so, further drilling in 1 or more areas.	Possible construction of plant, with continuing drilling and testing of wells.
Surprise Valley, CA	Approximately 7 holes drilled across several square miles; Magma Power, Gulf Oil; sites for 3 additional holes approved.	Continued drilling and testing; possible wildcat drilling in adjoining areas.	Possible decision to construct power plant; if so, further drilling.	
Long Valley, CA	Approximately 10 holes drilled in limited area; Magma Power; surface exploration continuing; drilling delayed because of environmental and leasing questions.	Leasing and drilling of additional holes; testing of wells.	Probable continued drilling and testing of wells.	Possible decision to construct power plant; if so, further drilling and testing of wells.
Beowawe, NV	Approximately 12 holes drilled in limited area; Magma Power, Chevron; additional holes planned.	Continued drilling and testing of wells; possible wildcat drilling in adjoining areas (Crescent Valley to south).	Possible decision to construct power plant; if so, further drilling and testing.	Possible construction of plant, with continued drilling and testing of wells.

Area	Development State	Forecast 1975-1976	1977-1979	1980-1985
		Low Enthalpy (<200 BTU/lb) Hot Water (T=225°-300°F)		
Klamath Falls, OR	Some 400 holes drilled into hot water aquifer; most utilized for space heating via heat exchanging with pure water; supplies heat to homes, schools, businesses for about 10,000 persons.	Continued occasional drilling and construction of facilities for space heating; possible deep drill hole to test higher enthalpy regime.	Probable continued drilling, with possibility of large-scale heat-exchange project.	Probable continued drilling and testing; possible development of higher enthalpy regime.
Raft River, ID	2 holes drilled in limited area; publicly sponsored research; testing and evaluating aquifer for possible application of binary-cycle heat exchanging.	Continued testing; possible drilling of additional holes.	Possible pilot development of heat-exchanging facilities; possible additional drilling	
Calistoga, CA	Over 60 wells produce hot water for space heating in area of 3 mi^2; 1 deep hole; numerous resorts.	Continued occasional drilling of holes for space heating.	Possible deep drill hole to test higher enthalpy regime; continued occasional drilling of holes for space heating.	
Amedee, CA	2 deep drill holes (Gulf Oil); use of hot water for greenhouse operations.	Possible continued drilling of holes for hot water.	Possible deep drill hole to test higher enthalpy regime.	
Susanville, CA	Publicly sponsored research into large-scale development of hot water heating system.	Possible drilling of 1 or more holes to test extent of thermal aquifer.	Possible drilling of additional holes.	Possible construction of pilot facilities to test suitability of development.
Steamboat Springs, NV	Dozens of shallow wells drilled along 20-mile long zone north to Reno; some used for space heating.	Possible continued drilling of holes for hot water; leasing of federal lands.	Possible deep drill hole to test higher enthalpy regime; continued drilling of holes for hot water.	
Boise, ID	2 wells in Boise supply hot water for space heating; publicly sponsored research underway into this thermal system.	Possible continued drilling of hot water wells.	Possible deep hole to test higher enthalpy regime; possible continuing drilling of hot water wells.	
		Geopressured Aquifers		
Gulf Coast, TX and LA	Evaluation of data from very deep oil and gas wells into hot water aquifers.	Probable continued evaluation of existing data.	Possible drilling of deep exploratory hole.	Possible continued drilling and testing of deep hot water aquifers.
		Hot Dry Rock		
Valles Caldera, NM	2 holes drilled west of Caldera as research project by Los Alamos Laboratory; testing and evaluation.	Continued testing and evaluation; probable attempt to generate fractures between holes by pumping water under great pressure.	Continued fracturing and evaluation of results; possible drilling of additional holes.	Possibility of decision to develop pilot facilities for heat exchanging in fractured holes.

In addition to these areas, exploratory test drilling may take place at some or all of the following geothermal targets between 1975 and 1977:

Black Rock Desert, NV
Dixie Valley, NV
Coso, CA
San Emidio, NV
Lakeview, OR
Alvord Desert, OR
Grand View, ID

Cove Fort, UT
Buena Vista, CO
Animas, NM
Borax Lake, CA
Bieber, CA
Wilbur Springs, CA
Crescent Valley, NV

Ruby Valley, NV
Crump-Adel, OR
Vale, OR
Weiser, ID
Mountain Home, ID
San Luis Valley, CO
Preston, ID
Beryl, UT

Surface exploration is underway at each of these sites, and at very many other places in the western U. S. Details of exploration, and even the precise locations, often are not available, because of the competitive nature of exploration and leasing of lands.

Table 24

EXPLORATION AND DEVELOPMENT
PRACTICE AND COSTS

Activity (Chronological)	Area Covered	Acreage Costs Unit ±50%	What is Done
Reconnaissance exploration	Tens of square kilometers or more	$ 2,000 (pennies per hectare	Reconnaissance geology and geochemistry, collection of published data, selection of targets for detailed exploration.
Unit Usually Leased at This Time (costs are usually between $1.00 and $20/hectare)			
Detailed exploration	Few square kilometers	$ 20,000 ($4 to $40 per hectare)	Detailed geologic mapping, detailed geochemistry, electrical surveys, passive seismic surveys, drilling of temperature-gradient holes, selection of drill sites for deep holes.
Exploratory drilling	Few hectares	$500,000 (wells cost from $0.3 to $1 million each)	Permitting of hole, preparation of drilling specifications, drilling and logging, testing, perhaps drilling additional holes.
Development	Few hundred hectares	Millions of dollars	Drilling of development wells, construction of development facilities.

CHAPTER 2

GEOTHERMAL LEASING

Part I - Federal Geothermal Leasing

The federal government controls geothermal resources on federal lands and under state or private lands where the federal government has retained mineral rights. Federal leasing is limited to lands controlled by the Bureau of Land Management (BLM), the Forest Service (USFS), and in some cases the Bureau of Reclamation (USBR). The Geologic Survey (USGS) will determine lease parcelling, royalty rates, safe operating procedures, and efficient use of geothermal resources. If geothermal resources are connected with mineral rights controlled by state or private entities, regulation is the responsibility of the state.

Leasing procedures involve cooperative agreements among federal agencies. There are three levels of guiding documents: 1) the Geothermal Steam Act of 1970 (PL 91-581), which expresses Congress's wishes for the use of geothermal resources; 2) a set of regulations promulgated by federal agencies having a designated role in leasing and regulation to guide fulfillment of their responsibilities under the act; 3) cooperative agreements between agencies, intended to minimize confusion of responsibilities. Cooperative agreements have coordinated the geothermal efforts of the USGS and BLM for several years. In June, 1976, a new cooperative agreement was adopted which formally included the Fish and Wildlife Service (USFWS) without significantly altering the basic character of the process. The Service is now included in the preparation of various environmental assessments and reviews of operations.

The formal agreement follows along with summary tables of the process.

MEMORANDUM OF UNDERSTANDING
FOR THE GEOTHERMAL PROGRAM

U. S. GEOLOGICAL SURVEY - BUREAU OF LAND MANAGEMENT -
U. S. FISH AND WILDLIFE SERVICE

COOPERATIVE PROCEDURES IN THE GEOTHERMAL PROGRAM

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MEMORANDUM OF UNDERSTANDING
FOR THE GEOTHERMAL PROGRAM

U. S. GEOLOGICAL SURVEY - BUREAU OF LAND MANAGEMENT -
U. S. FISH AND WILDLIFE SERVICE

The following guidelines are for the mutual cooperative efforts of the U. S. Geological Survey, Bureau of Land Management, and U. S. Fish and Wildlife Service in implementing the Federal geothermal resources program pursuant to the Geothermal Steam Act of 1970.

Abbreviations used hereafter for the various agencies, offices, and reports are as follows:

BLM	-	Bureau of Land Management
BLM-DO	-	Bureau of Land Management District Office
BLM-SO	-	Bureau of Land Management State Office
GS	-	U. S. Geological Survey
GS-RCM	-	U. S. Geological Survey, Regional Conservation Manager
AGS	-	Area Geothermal Supervisor
GS-AG	-	U. S. Geological Survey Area Geologist
GS-DG	-	U. S. Geological Survey District Geologist
FWS	-	Fish and Wildlife Service
FWS-RO	-	Fish and Wildlife Service Regional Office
FWS-AO	-	Fish and Wildlife Service Area Office
EAR	-	Environmental Analysis Record (prepared by BLM)
EA	-	Environmental Analysis (prepared by GS)
GEAP	-	Geothermal Environmental Advisory Panel (Sec. Order 2962)

1. Priorities and Scheduling of Lease Sales and Non-Competitive Leasing. (Primary responsibility - BLM)

Primary contacts will be the AGS, the FWS-RO, the BLM-SO involved.

(a) Competitive Lease Sale Scheduling.

BLM-SO may on its own motion, on recommendation from GS, or through nominations from industry, select areas for and schedule competitive lease sales in Known Geothermal Resource Areas (KGRA's). The BLM-SO will consult with GS-RCM as to KGRA leasing priorities, recommendations for lease stipulations, total area to be covered by the EAR, and overall priority and scheduling of the EAR and the sale. The BLM-SO will consult with FWS-AO and RO concerning fish and wildlife resources and related habitat, and regarding recommended stipulations and mitigating measures to protect these resources.

Generally, the areas to be covered by the EAR, prepared by BLM-DO, should include the maximum number of non-competitive lease applications in the vicinity of the KGRA. Determination of priority of scheduling lease sales will generally be based upon the geothermal potential of the area, its environmental sensitivity, and industry, interest. If nominations are either solicited or received from industry, BLM-SO will send an information copy of nominations to AGS, Menlo Park, and the FWS-AO.

(b) Scheduling for Non-Competitive Leasing.

Where non-competitive leasing only is involved, BLM-SO should consult with AGS and FWS-RO to determine area, priority, and scheduling of EAR's. Where withdrawn lands are involved, the BLM-SO shall consult with the appropriate land management agencies with the basic authority to permit leasing. The criteria for scheduling of EAR's to be prepared by the BLM-DO should include geothermal potential of the area, its environmental sensitivity, and industry interest. AGS will furnish, upon request by BLM-SO, a priority listing of potential geothermal areas with copies to the FWS-RO.

2. Environmental Analysis Considerations

(a) Pre-Lease Environmental Analysis Record (EAR). (Primary responsibility - (BLM)

(1) Upon initiation or revision of an EAR for either competitive or non-competitive leasing, BLM-DO will notify in writing the AGS and the FWS-AO of the area covered by the EAR. The AGS and FWS-AO will furnish BLM-DO with technical advice and information for consideration in the EAR, including recommended stipulations and mitigating measures. BLM-DO should specify deadline for such input with a minimum of 30 days advance notice. Maximum lead time should be provided.

(2) BLM-DO will furnish a copy of the draft EAR, with proposed special lease stipulations, to the AGS and FWS-AO and FWS-RO for review and comments prior to submission of EAR to BLM-SO.

(3) BLM-SO will furnish AGS the final BLM stipulations which are to be attached to non-competitive leases, or included in the notice of competitive lease sale, for the AGS review and concurrence with the stipulations. FWS-RO will be furnished a copy of the stipulations for review and comment.

(4) BLM-SO will furnish AGS and FWS-RO with two copies each of the final EAR.

(b) Post-Lease Environmental Analysis (EA). (Primary responsibility - AGS)

(1) For each proposal which requires a Plan of Operations, an Environmental Analysis (EA) will be prepared by the AGS. The AGS will request the technical advice on fish and wildlife matters, surface management, and environmental expertise of the BLM-SO and FWS-AO. The FWS-AO and the BLM-SO will provide technical advice and information in their areas of expertise to AGS for consideration in the EA which will include the recommended surface protection and reclamation requirements.

(2) When the GEAP chooses to review the draft EA, BLM-DO and FWS-RO will also be sent copies of the AGS draft EA for its review and comment.

(3) In every case, BLM-SO and FWS-AO and GEAP will be provided with a copy of the final EA.

3. Competitive Lease Sales. (Primary responsibility - BLM)

In steps (a) through (h) below, the GS contact will be the AGS, and the FWS contact the appropriate FWS-AO. In step (d) below, the BLM contact will be the BLM-DO involved. For all other lease sale matters, the appropriate BLM-SO involved will be the primary contact.

(a) To facilitate the sale procedure BLM-SO shall notify AGS and FWS-AO in writing at least 90 calendar days prior to sale date concerning:

(1) Areas within KGRA to be considered for competitive lease sale.

(2) Problems as they may relate to parceling; i.e., grandfather rights, environmentally sensitive areas (described by legal subdivision), pending law suits or restraining orders, etc.

(3) Any identifiable proposed lease stipulations even though there may be subsequent additions to or modification thereof.

(4) Request GS-RCM recommendations for parceling of tracts or leasing units and for rental and royalty rates at least 60 days prior to scheduled sale date.

(b) It will be BLM-SO responsibility to establish priority of processing and scheduling with input from the GS-RCM and FWS-RO.

(c) GS-RCM will recommend rental and royalty rates and parceling into tracts or leasing units for the competitive sale, submitting such information within 30 calendar days from date of request, whenever possible, to BLM-SO.

(d) EAR preparation will be the responsibility of the BLM-SO as outlined in Section 2(a).

(e) Publication of Lease-Sale Notice will be the responsibility of the BLM-SO. AGS concurrence must be received prior to publication. The BLM-SO will send a copy of the lease sale notice and lease stipulations to the AGS and the FWS-AO for final review, allowing at least 10 working days for comment.

(f) GS-RCM will prepare a pre-sale geothermal resources economic evaluation for all tracts in the sale. Prior to the scheduled sale the GS-RCM or his designee shall be available to meet with the BLM-SO and present the technical evaluation of the offered tracts and be prepared to discuss the geologic, engineering, and economic factors upon which the evaluation has been prepared.

(g) Immediately after the sale, the GS-RCM evaluation committee will meet to study the results of the sale. The committee will review its geologic, geophysical, economic and engineering data on all tracts and identify those tracts recommended for acceptance and for rejection supporting the recommendations with appropriate technical information. Immediately following this evaluation, the BLM-SO and GS-RCM committee will meet jointly and the GS-RCM or his designee shall present the GS technical evaluation of and recommendations on each tract for which bids have been received. The GS-RCM will submit his recommendations in writing to the BLM-SO.

(h) BLM-SO will send two copies of the executed lease, including lease terms, to the AGS for his records.

4. Non-Competitive Lease Applications (Primary responsibility - BLM)

(a) Serial Register Page.

The BLM-SO receives applications for non-competitive leases, prepares Serial Register Pages, and processes applications (at end of filing period) to determine if acceptable

and if lands are available. Where an agency other than BLM administers withdrawn or acquired lands, BLM-SO will obtain a title report from that agency. The BLM-SO will send information copy of Serial REgister Page to BLM-DO, AGS, and the FWS-AO.

(b) Competitive Interest Overlaps.

After reviewing each month's applications BLM-SO will send GS two copies (one to AGS and one direct to the GS-AG or GS-DG listed below) of those applications which result in competitive interest overlap as defined by 43 CFR 3200.0-5(k)(3); a copy of the land status plat showing applications and overlaps will also be sent to the GS-AG or GS-DG listed below. GS-RCM will review competitive interest overlap as soon as practical after receipt from BLM-SO. GS-RCM will notify BLM-SO as soon as KGRA's have been defined.

For Applications within States of:	Send Overlap Information to:
Montana	GS-DG, Billings, Montana
Wyoming	GS-AG, Casper, Wyoming
Utah	GS-DG, Salt Lake City, Utah
Colorado	GS-AG, Denver, Colorado
New Mexico	GS-AG, Roswell, New Mexico
Alaska	GS-AG, Anchorage, Alaska
California, Oregon, Washington, Idaho, Nevada, Arizona	GS-AG, Menlo Park, California
Eastern States	GS-AG, Washington, D. C.

(c) Environmental Considerations.

BLM-DO will prepare an EAR requesting input and technical advice and information from the AGS, the FWS-AO and other agencies as necessary.

(d) KGRA Clear Listing - Issuance of Lease.

BLM-SO will prepare lease forms and develop lease stipulations in consultation with the AGS, which will be sent to the AGS for final review and concurrence. Upon receipt of AGS concurrence, BLM-SO will forward lease form for applicant's signature. Upon receipt of lease signed by applicant, BLM-SO will forward lease forms to the AGS for final clear listing. The AGS will forward lease forms to the appropriate GS-AG or GS-DG who will then submit a KGRA clear listing report and return the lease forms to the BLM-SO. The GS-AG or GS-DG will also provide the AGS with an informational copy of the clear listing report. The BLM-SO will then issue the lease providing the AGS with two copies, including the stipulations.

5. Pre-Lease Exploration Permit (Primary responsibility - BLM)

(a) Upon receipt of a Notice of Intent to Conduct Geothermal Resources Exploration Operations, the BLM-DO will forward a copy of the Notice of Intent and any attachments to the AGS and the FWS-AO. This may include appropriate stipulation or documents relating to access routes across BLM lands.

The AGS and FWS-AO will notify the BLM-DO within five working days of any recommended stipulations considered desirable. The BLM-DO will send the AGS a copy of the approved permit.

(b) It will be the responsibility of the BLM-DO to see that the operator conducts exploration in accordance with regulations and terms of the permit. AGS and FWS-AO personnel are available, on request, to assist in supervision of operations under such permit.

(c) The BLM-DO will send the AGS a copy of the Notice of Completion of Exploration Operations for his records (Form 3200-10).

6. Post-Lease Notice of Intent to Conduct Geothermal Resources Exploration Operations (Primary responsibility - GS)

(a) Upon receipt of a Notice of Intent to Conduct Geothermal Resource Exploration Operations from an operator on an existing lease (as required by 30 CFR 270.78), the AGS will immediately forward a copy of the Notice and the required Plan of Operation to the BLM-DO and FWS-AO. The BLM-DO and FWS-AO will recommend any additional surface protection, reclamation requirements, and fish and wildlife protection measures including mitigations within their area of expertise.

(b) Upon receipt of the Notice of Intent and the required Plan of operation, an Environmental Analysis (EA) will be prepared by the AGS.

(c) It will be the responsibility of the AGS to see that exploratory operations on the lease concerned are conducted in accordance with regulations, GRO Orders, the approved Plan of Operation and Notice of Intent. The AGS will notify the BLM-DO in writing if the permittee does not comply with surface protection, fish and wildlife protection measures, reclamation requirements, and the corrective action taken or recommended. In cases of emergency, where serious surface or environmental damage occurs, or appears imminent, the BLM-DO may, if the AGS or his representative is not immediately available, issue a stop order to the lessee or his representative and then immediately notify the AGS.

7. Plan of Operation and Application for Permit to Drill (APD) (Primary responsibility - GS)

(a) Upon receipt by the AGS of an Application for Permit to Drill, the AGS will immediately send a copy of the Plan of Operation (per 30 CFR 270.34) and APD (form 9-331C with proprietary information deleted as necessary) to the BLM-DO, the FWS-AO and the FWS-RO.

(b) For exploratory wells, and for all other drilling operations where GS, BLM, or FWS considers such necessary, the AGS will schedule with BLM-DO, FWS-AO, and the operator, a joint on-site inspection and discussion of the proposed operation and proposed access routes over BLM lands. The operator will normally be encouraged to discuss the proposed action and conduct the on-site inspection with the BLM-DO, AGS, and FWS-AO, prior to writing his drilling program and Plan of Operation.

(c) If BLM-DO, FWS-AO, or AGS consider that additional information is necessary in the Plan of Operation, the AGS shall request the operator to provide such input as deemed necessary.

(d) When such additional information is requested, the operator will submit a final Plan of Operation or supplements to the Plan of Operation to the AGS who will forward a copy of same to BLM-DO and the FWS-AO.

(e) The BLM-DO and the FWS-AO will notify the AGS in writing of any special conditions which are recommended for inclusion in the approved plan of Operation.

(f) Upon receipt of the Plan of Operation, an EA will be prepared by the AGS. The EA prepared for subsequent well operations or for the post-lease Notice of Intent to Conduct Geothermal Resource Exploration Operation may vary in level of detail depending on the nature of the operation, the sensitivity of the area, and other appropriate considerations.

(g) The AGS will prepare and sign a letter of approval of the Plan of Operation containing conditions of approval mutually agreeable to both the BLM-DO and the AGS, and send the signed letter to the BLM-DO for approval.

(h) BLM-DO will sign the letter to complete the joint approval of Plan of Operation and forward an approved copy to lessee and an executed copy to the AGS and FWS-AO. The BLM-DO also forwards other documents relating to access over BLM lands outside the leased area to the operator with an information copy to the AGS and FWS-AO.

(i) The AGS will then approve the Application for Permit to Drill (Form 9-331C) and furnish a copy to the BLM-DO and the FWS-AO.

(j) The AGS will be responsible for compliance inspections of all operations conducted under the Plan of Operation and Application to Drill in the Area of Operations. However, BLM-DO and FWS-AO may inspect operations to assure conditions of the approved Plan of Operation are being met and will notify AGS of any non-compliance observed. The AGS will seek and utilize BLM-DO and the FWS-AO on surface management reclamation and fish and wildlife matters, and will request inspection assistance when considered necessary within their areas of expertise. AGS is the sole contact with operators except in cases of emergency. BLM-DO may issue instructions, notices, or orders to the operator only under the following emergency circumstances and conditions: (1) emergency situation exists that clearly threatens immediate serious or irreparable damage to the environment and resources or to the health and safety of employees and/or the public; or (2) the AGS representative is not timely available to take the necessary immediate action. The BLM-DO may in such emergency situations order the immediate cessation or correction of activities responsible for the emergency situation and may order repair or correction of damages, such orders to be followed by prompt telephoned and documented notification to the AGS of the action taken. BLM-DO will be responsible for all activities outside the Area of Operation, within the leasehold.

(k) Any desired significant changes in a Plan of Operation must be jointly approved by both BLM-DO and AGS.

8. Plans of Operation for Surface Installations or Subsequent Well Work

A Plan of Operation as per 30 CFR 270.34 will be required for all surface construction operations and subsequent well work. Procedure for approval will be as per 7(a) through (h) above. Joint on-site inspections may not be required, unless specifically considered necessary by AGS, BLM-DO, or FWS-AO. The AGS will be responsible for compliance inspections in the Area of Operations. BLM will have the same option covered in 7(j).

9. Plans of Development, Injection, or Production

The operator will be required to submit (1) a Plan of Development prior to entering the development stage of its operation as determined by mutual agreement between the operator and the AGS, (2) a Plan of Injection where fluid injection is proposed, and (3) a Plan for Production prior to commencing production for commercial utilization of the geothermal resource. Procedure for joint BLM-DO and AGS approval will be essentially as per 7(a) through (h), described above for the Plan of Operation. The AGS will be responsible for compliance inspections in the Area of Operations.

10. Designation of Operator

The AGS will furnish BLM-DO a copy of any Designation of Operator received.

11. Filing and Termination of Bonds

(a) BLM-SO will routinely advise the AGS of the filing of any lease compliance (3206.1-1(b)) or protection bonds (3206.1-1(c)). The AGS will not permit operations on a lease until advised by BLM-SO that such bonds have been filed.

(b) The period of liability under any bond shall not be terminated by BLM until the AGS has advised the BLM-SO and FWS-AO that all terms and conditions, insofar as operations on the lease are concerned, have been fulfilled.

12. Relinquishments

BLM-SO will furnish the AGS a copy of any lease relinquishment filed. The AGS will furnish BLM-SO and the FWS-RO a report as to satisfactory restoration and abandonment of any affected portion of leased lands.

13. Annual Environmental Report

The AGS will furnish the BLM-DO a copy of the lessee's annual report of compliance with environmental protection requirements as required under 30 CFR 270.76. These reports will be available for inspection at either office for FWS-AO inspection.

14. Annual Report of Diligent Exploration

AGS will advise BLM-SO of the amount of expenditures considered qualified for diligent exploration pursuant to 43 CFR 3203.5.

15. Designation of Coordinating Offices for Purposes of the Memorandum

(a) For the U. S. Geological Survey, the office of the Assistant Division Chief of Operations, Conservation Division is designated as the coordinating office.

(b) For the Bureau of Land Management, the Division of Minerals Resources is designated as the coordinating office.

(c) For the U. S. Fish and Wildlife Service, the Office of Biological Services is designated as the coordinating office.

16. General Provisions

All assistance rendered under this Agreement will be carried out in full compliance with the objectives, policies, and responsibilities of the Department. Any unresolved matters concerning geothermal program where there is a mutual interest shall be referred for resolution to the next supervisory level involved.

The above cooperative procedures are in accord with S.O. 2948 between BLM and GS and supersede all other implementing cooperative procedures involving geothermal leasing, administration, and supervision.

The AGS, BLM-SO and FWS-RO will meet, as necessary, to surface internal problems which occur as a result of implementing the requirements of this Agreement and to develop strategies for mitigating those problems.

This Agreement shall become effective upon execution hereof by the Directors. At least three months prior to the first and subsequent anniversary dates hereof, the AGS, BLM-SO, and FWS-RO shall apprise their respective coordinating offices of any suggested modifications in this Agreement which would improve its workability, reduce duplication of effort, and enhance the ability of the Department to perform its assigned functions relating to the leasing of Federal lands for geothermal resources and approval of operations in a more timely manner.

/s/ GEORGE W. MILIAS — 6/7/76
Acting Director, Fish and Wildlife Service — Date

/s/ GEORGE L. TURCOTT — 5/28/76
Acting Director, Bureau of Land Management — Date

/s/ W. A. RADLINSKI — 6/1/76
Acting Director, Geological Survey — Date

Table 25

SUMMARY OF NOTICE OF INTENT PROCEDURES

Operator	USGS	Surface Management Agency (BLM/USFS/USBR)	U. S. Fish and Wildlife Service
Through field investigation, identify lands deserving of more intensive investigation not within normal use of public lands. Activities required are likely to impair land surface or fish and wildlife or habitat resources.			
Develops Notice of Intent for Permit to Conduct Exploration Operation (geothermal resources) which includes the description, location, and date of proposed activities. Submits Notice of Intent to the appropriate surface management agency. A bond is required with the Notice of Intent.			
		Reviews Notice of Intent for possible damage to land surface or resources, and for conformance to the multiple-use management responsibilities of the surface management agency. Submits Notice of Intent to the USGS for review. Bond is held.	
	Reviews Notice of Intent for safety and subsurface resource protection elements of the proposed activities. Recommends safety stipulations.		Reviews Notice of Intent for fish and wildlife resources protection. Recommends operational and rehabilitation requirements.
		Develops a set of stipulations to ensure safe and environmentally nondisruptive activities. Approves Notice of Intent. Thirty calendar days are allowed for review and determination.	
Conducts exploration activities. Upon completion of activities, submits a Notice of Completion of Exploration Operations to the surface management agency.			
		Reviews Notice of Completion and inspects lands to ensure that the stipulations were carried out satisfactorily.	
	Reviews Notice of Completion for protection of subsurface resources. Submits recommendations to the surface management agency.		Reviews Notice of Completion for protection of fish and wildlife resources and rehabilitation methods.
		Additional measures may be required of the operator. Ninety calendar days are allowed for this review. Surety bond is released upon satisfactory completion of requirements.	
	The Notice of Completion is held for files.		

Table 26

SUMMARY OF COMPETITIVE LEASING

Operator	USGS	BLM (and/or Surface Management Agency)	U. S. Fish and Wildlife Service
	Designates KGRAs from geologic information and non-competitive lease overlapping interests. List is published in Federal Register.		
		BLM-USFS-USBR-USGS develop priority listing of KGRAs to schedule processing and lease sales.	
	Provides geological information for the EAR process.	Surface management agency (BLM-USGS-USBR) develops an EAR on KGRAs and formulates special lease stipulations.	Provides fish, wildlife and ecological information for the EAR process.
	Reviews EAR, adding special USGS lease stipulations. Recommends parcelling, rent and royalty rates.		Reviews EAR for special lease stipulations regarding fish and wildlife.
		BLM state office publishes lease-sale notice.	
	Provides a pre-sale geothermal resource economic evaluation.		
		BLM state office holds lease sale.	
Bids are made on tracts within KGRAs.			
	Evaluation committee reviews bids and recommends acceptance or rejection.		
		BLM state office accepts or rejects bid.	
Highest bidder for a given tract submits Plan of Exploration.			
		BLM district office reviews Plan of Exploration for conformance with the EAR special stipulations. Copies are distributed to USGS and the surface management agency.	
		BLM state office prepares lease for highest bidder.	
Highest bidder signs lease and submits surety bond.			
		BLM state office issues lease and sends copies to USGS and the surface management agency.	

Table 27

SUMMARY OF NON-COMPETITIVE LEASING

Operator	USGS	BLM (and/or Surface Management Agency)	U. S. Fish and Wildlife Service
Through casual or Notice of Intent explorations, determines to lease lands which may be outside established KGRAs.			
Submits an application for non-competitive lease with complete description of lands to BLM.			
		BLM prepares serial register page and distributes it to USGS and to the appropriate surface management agency.	
		BLM screens applications of the current calendar period for overlap of interest. Refers areas with 50 percent overlap to USGS for KGRA designation. Refers areas to USGS for KGRA clearance.	
	USGS designates KGRAs when 50 percent overlap is involved. Applications are reviewed to determine if they are, in whole or in part, part of an existing KGRA.		
The operators who submitted applications which did not receive KGRA designation must submit a Plan of Exploration to BLM.			
		BLM distributes the Plan of Exploration to USGS and the surface management agency.	
	USGS provides geological and hydrological input to the EAR process.	The surface management agency conducts an EAR on the lands proposed for lease. Special lease stipulations are developed.	Provides fish and wildlife and ecological information for the EAR process.
	USGS reviews the EAR and adds special stipulations appropriate to drilling.		Reviews EAR for special lease stipulations regarding fish and wildlife.
		BLM prepares a lease with special stipulations and submits to operator for signing.	
Operator signs lease form and submits surety bond to BLM.			
		BLM forwards application to USGS for final KGRA clearing.	
	USGS reviews application to determine if it is part of an existing KGRA and for final concurrence with the stipulations.		
		BLM signs and issues non-competitive lease.	
Lessee is notified.			
		BLM distributes copies of the lease to USGS and surface management agency.	

Part II - U. S. Fish and Wildlife Service Interaction with Geothermal Development Activity on State and Private Lands

The Service has authority to assess fish, wildlife, and habitat impacts, and prescribe mitigation, whenever any activity requires federal action or permit. When activity is private or state, and on private or state lands, Service involvement is limited to merely supplying information. However, since in most states the Service is viewed as an important information source, and its help is sought by local and state agencies and concerned private organizations, there is always an opportunity to influence a proposed project, even if in an informal role.

If the activity is on private or state land and does not require a license or permit *per se*, the Service is directed to be involved if the proposed project constitutes a possible impact to an endangered or threatened species or that species' habitat. ("Endangered" is defined as a species in danger of extinction throughout all or a significant portion of its range, and "threatened" as a species likely to become endangered in the foreseeable future.) The Service is authorized to acquire lands containing habitat resources which, if lost, would create additional pressure on endangered or threatened species. If the state has passed legislation similar to the federal Endangered Species Act of 1973, the Service may make funds available to the state for the acquisition and management of appropriate habitat lands.

When geothermal development is proposed on private or state lands, with federal lands near-by, and when impacts on the private or state lands may affect fish, wildlife, and habitat of federal lands, the form of Service involvement is an agreement with the state fish and game department on joint studies, and reciprocal respect for fish, wildlife, and habitat concerns.

CHAPTER 3

ENVIRONMENTAL ASSESSMENT PROCEDURES FOR FISH AND WILDLIFE RESOURCES

Several steps in the general evolution of geothermal development on federal lands have environmental assessment requirements. Each assessment has an element which analyzes proposed activities and possible impacts on fish and wildlife. It is important the fish and wildlife analysis 1) be at a level of detail appropriate for the assessment phase, 2) be compatible with and interact with other elements of the assessment phase being conducted by other federal agencies, and 3) be designed to provide a factual basis for future and more detailed assessments.

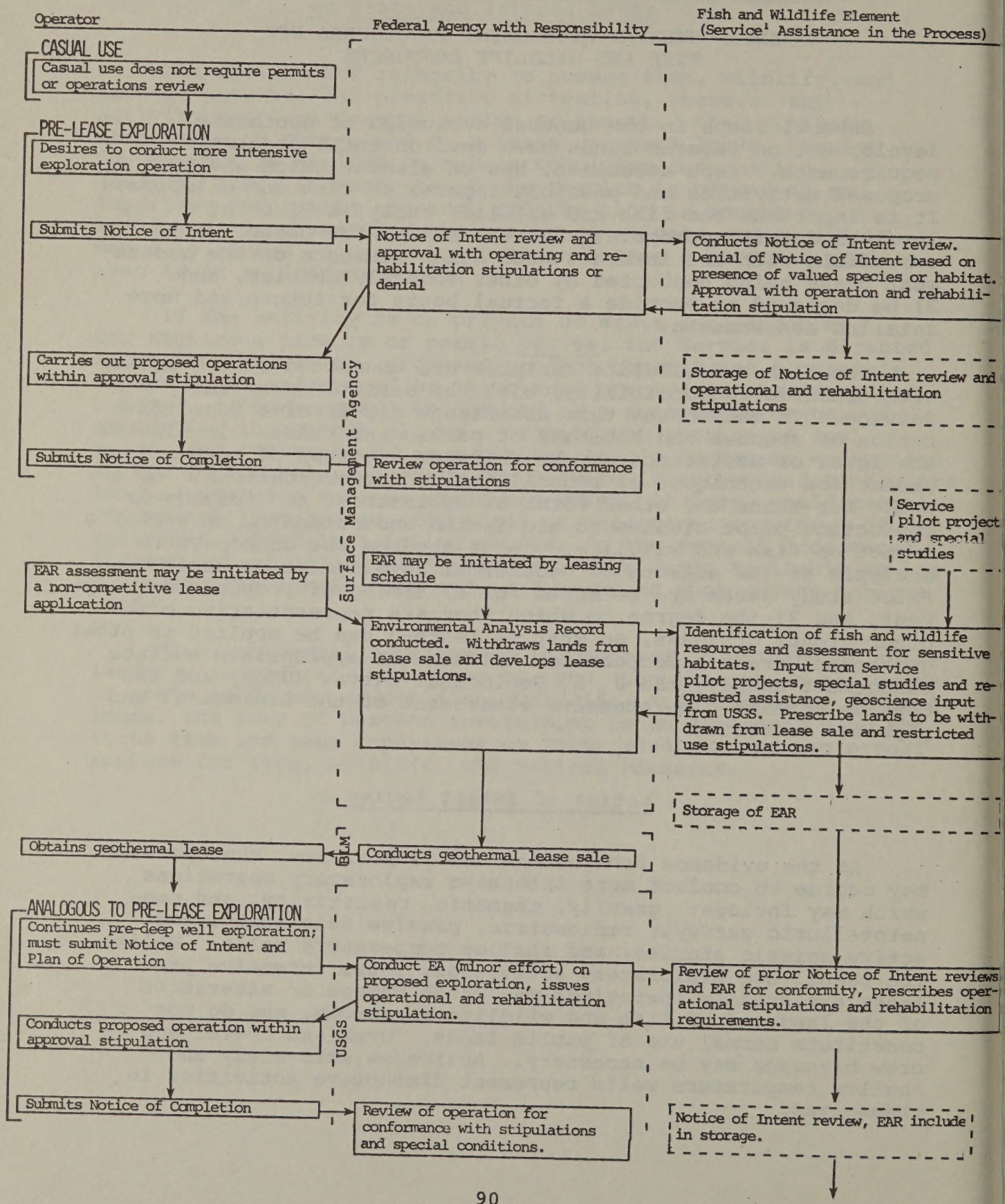
The fish and wildlife analyses are conducted by the agency with specific responsibility, with the assistance of the Service. In many cases this assistance may involve identification of species and habitats of particular value. In others, the level of assistance may be guidance in terms of appropriate protection techniques or rehabilitative recommendations. As a basis for these and other forms of assistance, the Service is conducting pilot studies to aid in the understanding of probable impact on fish and wildlife. These studies are an ecosystem analysis of the effects of geothermal development on habitat. Pilot study areas are selected for 1) timing of probable development, and 2) the degree to which they are representative of other groups of KGRAs, so what is learned can be applied to other geothermal areas. Cooperation between the appropriate surface management agency, the U. S. Geological Survey (USGS) and the Service permits comprehensive assessment of the biological and physical ecosystem.

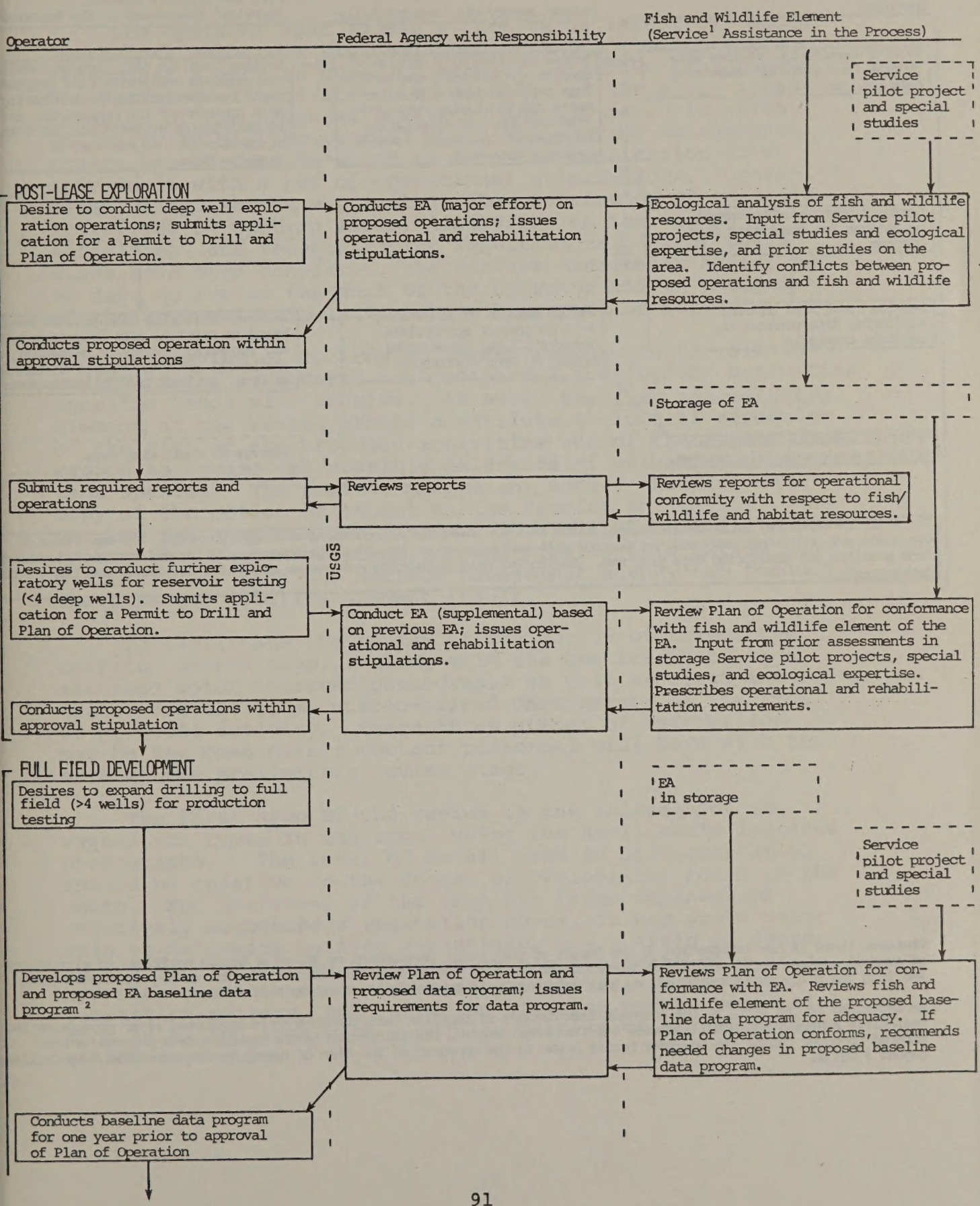
Notice of Intent Review

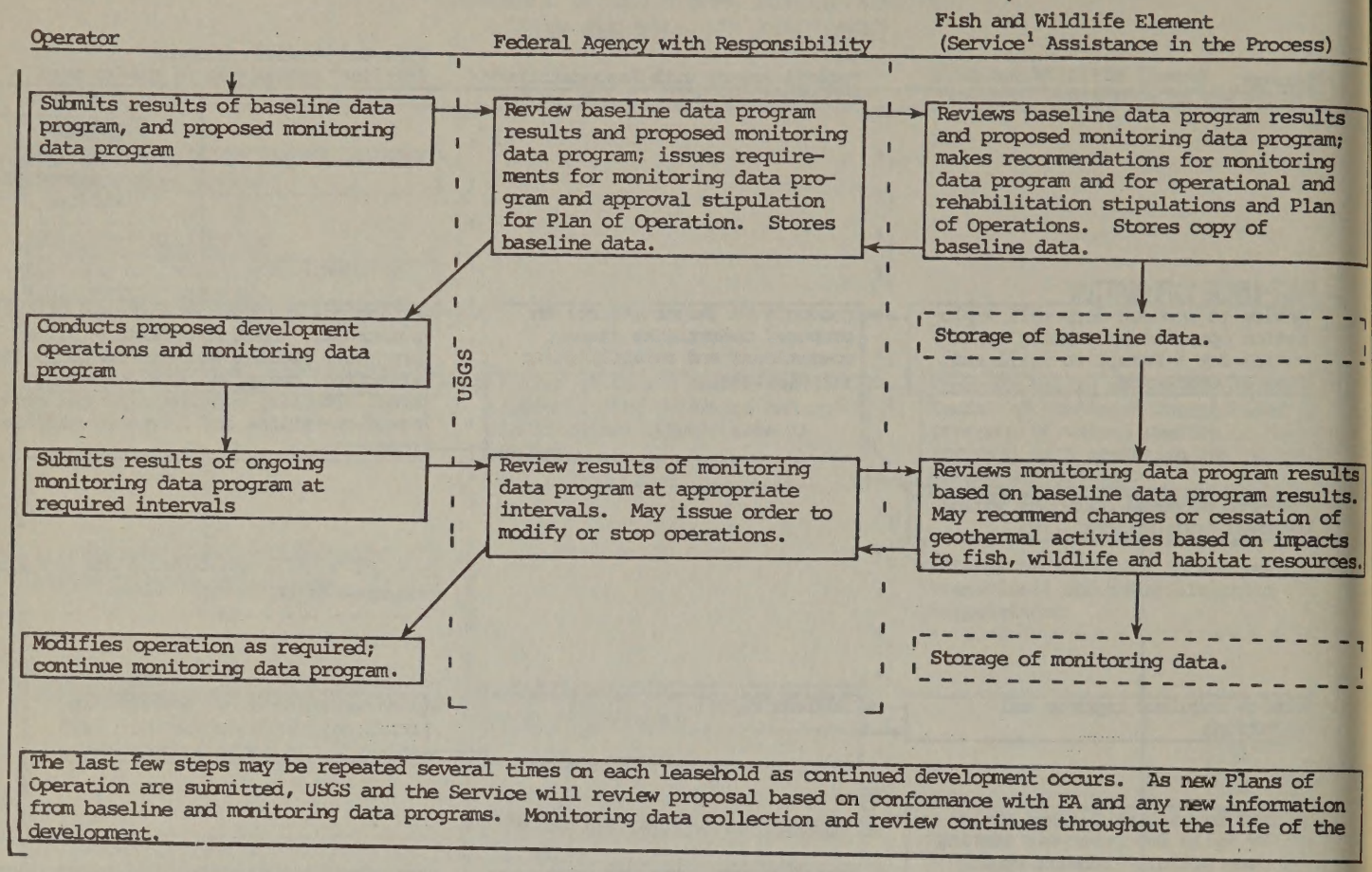
If the evidence from casual use is positive, the operator may decide to conduct more intensive exploratory operations which may include: gravity, magnetic, resistivity, and magnetotelluric surveys; radiometric, passive seismicity, and active seismic studies; and shallow temperature wells. Unlike the casual use exploratory activities, these intensive prelease exploratory operations may cause damage or alteration of the land and of fish and wildlife resources, and do not constitute normal use of public lands. Overland travel and crew bivouacs may be necessary. Active seismic study and shallow temperature wells represent disruptive activities in themselves.

TABLE 28

SEQUENCE OF GEOTHERMAL DEVELOPMENT AND FISH AND WILDLIFE ASSESSMENT




Operator
Federal Agency with Responsibility
Fish and Wildlife Element (Service[1] Assistance in the Process)
Service pilot project and special studies
POST-LEASE EXPLORATION
Desire to conduct deep well exploration operations; submits application for a Permit to Drill and Plan of Operation.
Conducts EA (major effort) on proposed operations; issues operational and rehabilitation stipulations.
Ecological analysis of fish and wildlife resources. Input from Service pilot projects, special studies and ecological expertise, and prior studies on the area. Identify conflicts between proposed operations and fish and wildlife resources.
Conducts proposed operation within approval stipulations
Storage of EA
Submits required reports and operations
Reviews reports
Reviews reports for operational conformity with respect to fish/wildlife and habitat resources.
USGS
Desires to conduct further exploratory wells for reservoir testing (<4 deep wells). Submits application for a Permit to Drill and Plan of Operation.
Conduct EA (supplemental) based on previous EA; issues operational and rehabilitation stipulations.
Review Plan of Operation for conformance with fish and wildlife element of the EA. Input from prior assessments in storage Service pilot projects, special studies, and ecological expertise. Prescribes operational and rehabilitation requirements.
Conducts proposed operations within approval stipulation
FULL FIELD DEVELOPMENT
Desires to expand drilling to full field (>4 wells) for production testing
EA in storage
Service pilot project and special studies
Develops proposed Plan of Operation and proposed EA baseline data program [2]
Review Plan of Operation and proposed data program; issues requirements for data program.
Reviews Plan of Operation for conformance with EA. Reviews fish and wildlife element of the proposed baseline data program for adequacy. If Plan of Operation conforms, recommends needed changes in proposed baseline data program.
Conducts baseline data program for one year prior to approval of Plan of Operation



[1] Whenever there is new information on the impact of geothermal development on specific biotic entities, or alterations of general environmental conditions, it should be fed into the Service information file for subsequent assessments, and into the pilot project studies, so that information is available to other Service offices.

[2] As explained in the text, to the economic/risk demands of baseline data programs to be conducted after production is reasonably assured, and predisturbance baseline requirements, the initiation of the baseline data program is considered to occur during the one-year period prior to the approval of the Plan of Operation for expanding deep drilling beyond 4 wells.

The operator must submit a "Notice of Intent to Conduct Geothermal Resources Exploration Operations" to the surface management agency in order to conduct intensive exploration. The Notice of Intent lists the location of the site, a description of the proposed activity, and the dates in which the activity will be carried out. The surface management agency has 30 days in which to deny the application or to approve it with a set of operational stipulations. Operational stipulations may include the restriction of specific activities on certain lands, limitation on the timing of activities, and rehabilitation requirements. After operations have been completed, the surface management agency has 90 days to review the work of the operator and to determine if the approval stipulations have been carried out.

The review of Notices of Intent represents the first environmental assessment for geothermal development activities specific lands will receive. As such, the fish and wildlife element of the review should constitute an initial screening of the site of the proposed activities and of the surrounding region to locate the possible existence of valuable or important species. The surface management agency should send a copy of the Notice of Intent to the Service for review. The Service can complete the fish and wildlife element and make appropriate recommendations, or can provide information and evaluation so that the surface management agency can conduct the fish and wildlife element itself.

To facilitate the review of the Notice of Intent the operator should supply, along with the required map, high altitude color infrared photographs as well as black and white, low-altitude, stereo-paired photographs of the area of proposed activity. These three pieces of information may be the most direct contact personnel will have with the site at the preliminary review stage.

The first step of the review is the delineation of vegetation types in the area, using the small-scale infrared photographs. The level of detail used in differentiating should be relative to the degree of variability found on the photo. For instance, if the area has large expanses of relatively homogeneous vegetation cover, it may prove valuable to delineate noticed variations, e.g., areas of denser vegetation indicating variation in micro-climate soil or hydrologic conditions. In areas where there is a complex vegetation pattern, some clumping of types may be beneficial, such as a land area with a regular pattern of sage-forest-meadow vegetation.

Second, the vegetation pattern immediately around the area of activity should be noted, using both small-scale infrared and large-scale black and white stereo-paired photographs. A comparison should be made with what was delineated in the first step. If it is determined that the activity site has unusual vegetation features relative to the region, they should be given special consideration.

The next step is the application of professional judgment, using readily available published information, and quick contact with various persons considered knowledgeable in the area, to develop a list of species that may be found in that particular region, given the delineated vegetation types. The list should be distilled to those species that are considered to be of concern to the Service. As in all steps which require the identification of specific species of concern, a varied set of values must be employed. Some may refer to explicit criteria (threatened or endangered species), while others may be based on such judgments as the abundance of the species or habitat relative to the regional context. The latter judgment does not allow for explicit guidelines, nor does the judgment of a species' ecological importance, and it is best made by the field professional.

Those species that are noted as being of concern should be keyed to those habitats that are important to them, and, if appropriate, to the season in which particular habitats are important. It is expected that this will become a task requiring less time as background information is developed and as multiple analyses are carried out.

In the fourth step, proximity of the proposed site of exploratory activity to any of the delineated habitats of concern should be noted. If the site is within or near any of these habitats or is in a position to transmit impact to a delineated habitat (such as downstream), the timing of the activity should be considered to determine if the specific habitats are important to the species of concern at the time of the proposed exploratory operation.

- If the proposed activity is in conflict with a habitat, but not in conflict with the timing of the habitat's use, operational and rehabilitation recommendations should be made to reduce the possible impact of the activity on the habitat.
- If the proposed activity is in conflict with both the habitat and the timing of the habitat's use, the Service should make recommendations to alter the timing or location of activities.

Table 29

NOTICE OF INTENT REVIEW
FISH AND WILDLIFE ELEMENT

Surface Management Agency	Fish and Wildlife Element Notice of Intent Review (Surface Management Agency with Assistance from Service)	Information Input/Output (Service Assistance to Surface Management Agency)
Receives Notice of Intent and initiates Notice of Intent review		
	Delineate vegetation types in the area using CIR photography	← Prior Notice of Intent reviews in area that are on file
	↓ Delineate vegetation types in location of proposed activity using CIR and large-scale stereo pair photography	
	↓ Compare local with regional vegetation for unusual occurrence	
	↓ Develop list of species expected in area given biome and vegetation delineated	← Publications, experts, prior reviews, Service pilot projects
	↓ Screen list for those species considered important	
	↓ Check for conformation of species inhabiting area	← Publications, experts, prior reviews
	↓ Develop habitat requirements for this screened list	← Publications, experts, prior reviews, Service pilot projects
	↓ Delineate areas of concern	
	↓ Compare activity location with delineated areas of concern	
	↓ Analyze activity for general impact to fish/wildlife and habitat	→ File entire package for future use
	↓ Prescribe operational and rehabilitation requirements	
← Input to general Notice of Intent review of the fish and wildlife element findings; denial based on sensitive location, or approval with operational and rehabilitation requirements for fish and wildlife protection		

- If the habitat is that of a threatened or endangered species, the Service should recommend alternative locations, based on the review of the map and small-scale infrared photography.
- If the site of the proposed activity is not in conflict with habitats or species of concern, the Service should turn to the analysis of the large-scale, stereo-paired photographs.
- If activity on the site itself will not adversely affect a species or habitat of concern, but more intensive or widespread operations may, the operator should be notified of the fact that future operations may be restricted. It is appropriate to recommend against approval on this basis.

The fifth step is a level of analysis concerned with site specific considerations. This stage is to be applied to sites which have not yet been eliminated as potentially sensitive. Still of importance are general considerations of habitat and environmental quality. In cases of site disturbance, the proposed operation should be assessed for its possible effect on the specific location as well as the possibility of translocation of the effect. The large-scale stereo-paired photographs should be used for this analysis.

For impacts expected, site specific recommendations should be made for mitigation of the impacts by either alteration of the operation or by explicit activities. (This may include rehabilitation requirements.) Hydrologic systems may represent the route by which impacts may be translocated. Therefore, some emphasis should be placed on hydrologic parameters. Erosion and subsequent sedimentation could represent a significant impact to downstream habitats, and a short-term effect on groundwater quality could affect the quality of nearby springs.

From what has been determined from the five basic steps of this analysis, areas are delineated which have been found to preclude activity, restricted by a timing element, or that are such as to require special care by operators. As examples:

- Due to limited springs and watering areas, springs and the area immediately upslope are restricted from activities which may affect groundwater. (Shallow temperature gradient drilling, crew bivouac, etc.)
- Due to potentially erodible stream banks, vehicle travel may be limited to specific stream crossings.

- Due to the importance of downstream habitat, the riparian areas upstream will be limited to those activities which will not cause increased runoff or soil erosion.
- Due to the proximity of nesting raptors, operations should be conducted only after the nesting season.

These are only a few examples of the restrictions which may be used in controlling the location, timing, and possibly the method of operation. Although a list of possible conditions which could warrant alteration of the proposal would be extensive, it may be found that those which would be restrictive in individual cases would be limited in number.

Besides the review of place, time, and mode of exploratory operations, a second purpose of the Notice of Intent approval stipulations is to prescribe surface rehabilitation techniques to be employed by the operator. In those areas where activities have received approval, a set of rehabilitation requirements should be prescribed and recommended to the surface management agency for inclusion in the approval stipulations. These recommendations may include such things as revegetation with specific plants to provide short-term feed or cover for local species, and the regrading and revegetation of access roads to limit user access to potentially sensitive areas.

The recommendations which are generated are submitted to the appropriate surface management agency office, and at this point areas of conflict between the concerns of the Service and the surface management agency are negotiated. When agreement is developed, the surface management agency assumes the responsibility of issuing the approval conditions (or the denial) and to follow up the activities to ensure that the requirements are followed.

As Notice of Intent reviews are completed, the information delineated by the assessment process should be kept on file. The vegetation types determined through the small-scale color infrared photography and unusual habitats delineated should be shown on a map of a standard scale (possibly 1:24,000). Also shown on this map will be those areas which received some degree of restriction. In report form, a copy of the operational stipulation and rehabilitation requirements should be kept. It may prove valuable to organize the mitigation and rehabilitation recommendations by specific vegetation site type or by some other natural parameter. As information on the success of the requirements is received, it should be entered into the file.

This information should be filed using some natural descriptor for categorizations, such as biome types or physiography, so that when subsequent Notice of Intent reviews must be conducted, past surveys can provide information to shorten processing time. The Notice of Intent reviews also act as the first level of analysis for the studies conducted at the Environmental Analysis Record stage and therefore the Notice of Intent reviews must be readily available.

Although the first few Notice of Intent reviews may require more than one working day to complete, it is expected that the time required will be reduced as internal procedures, background information, and outside expert contacts are developed.

Environmental Analysis Record

As operators apply for non-competitive leases or a KGRA is scheduled for competitive lease sales, the appropriate surface management agency must conduct an Environmental Analysis Record (EAR). An EAR is an analysis of the area to be leased in terms of the environmental, socio-economic, and land use impacts of the sale. With respect to the control and management of geothermal resource development, the prime purposes of the EAR are the identification and withdrawal of sensitive lands which may be adversely impacted to an unmitigable degree, and the attachment of general lease stipulations to other appropriate lands where needed. This allows for the early protection of fish and wildlife resources.

Although the surface management agency will conduct the major part of the EAR, geological and hydrological information may come from the USGS, and information may be requested from other federal and state agencies. It is critical that the Service join in the EAR effort, because it is at this point in geothermal development that lands which are determined too sensitive to the expected activities are withdrawn from the lease sale. The feasibility study proposed here is designed to be compatible with the surface management agency's EAR.

One of the first activities of the EAR process is a joint on-site inspection of the area by the land management agency, the USGS, other interested agencies, including the Service, and, in the case of non-competitive lease situations, the prospective operator. It is important that the Service attend this inspection so that direct contact is made with the

Table 30

ENVIRONMENTAL ANALYSIS RECORD
FISH AND WILDLIFE ELEMENT

Surface Management Agency	Fish and Wildlife Element of EAR Process (with Assistance from Service)	Information Input/Output (Service Assistance to the Surface Management Agency)
Initiation of EAR process, development of other elements of the EAR	Review files of Notice of Intent reviews and appropriate pilot projects to identify possible conflicts between development and fish/wildlife and habitat resources	← Files of appropriate Notice of Intent reviews and pilot projects
	↓ Joint on-site inspection; present possible points of fish/wildlife and habitat conflict with development. Delineate study area and identify data needs.	
	↓ Delineate vegetation types in the study area using CIR photography	← Prior Notice of Intent reviews
	↓ Develop species list and screen for importance	← Publications, experts, prior reviews, Service pilot projects
	↓ Identify habitat requirements of important species	← Publications, experts, Service pilot projects
	↓ Locate habitats of concern (first order sensitive areas); identify potential habitats of important species	
Soil, geologic, hydrologic, and other information →	Identify second order sensitive areas	← Service pilot projects
	↓	
Input to general EAR of fish and wildlife element findings; area to be withdrawn because of sensitive habitat and prescribed lease stipulations to prevent damage to habitats and species by development ←	Determine areas to be withdrawn and prescribe lease stipulation of lands open for lease sale	→ File entire package for future use

other agencies involved. At this time the area is reviewed to determine the actual surface area to be covered by the EAR. Also, some cooperative understanding of the area's general sensitivity to geothermal activity is approached, and points of particular concern are tentatively identified. If there are special tasks or important questions to be addressed, the coordination of the effort can be initiated at this time.

When Service personnel attend the on-site meeting, they should have a first-level assessment of the area in hand. As it is likely that prior to this point at least one, or more likely, many exploratory operations under Notices of Intent will have been conducted within or near the area of study, a file of the reviews should be available. Items of information from the file which are useful at this stage are: 1) the maps which have basic vegetation units delineated, 2) a list of possible species of the area, 3) a list of species which may have special value to the Service, and 4) a map delineating the possible location or habitat of species of concern. Prior to the meeting a resume should be developed which identifies the tasks or issues which the Service feels may be important. If possible, it would be advantageous to have already obtained a set of high altitude color infrared photos sufficient to cover the possible area of study and the surrounding region. The need for this information and understanding means that the Service should maintain a file of the Notice of Intent reviews, regardless of its level of input to the surface management agency.

Other documents which may be on file and otherwise available to the Service are previously conducted EAR's in areas of similar environmental characteristics, and Service pilot projects and special studies.

From the resume, it should be clear to the other members of the on-site inspection team 1) what species of possible concern to the Service may be in the area, and 2) what methodologies (or recommended methodologies) and direction of assessment the Service will pursue to assist the surface management agency. This will allow understanding of how the fish and wildlife elements will interface with other elements of the EAR.

After on-site inspection, a base map should be obtained from the surface management agency or prepared from USGS topographic maps and altered to the same scale as the surface management agency's base map. When preparing base maps, care should be taken to ensure that the map projections of the prepared map and the surface management agency's

base map are compatible. If the surface management agency's base map does not include regional features that the Service feels could be significant, an additional map of a smaller scale can be prepared to cover both the study area and the surrounding region. However, this issue should be resolved at the on-site inspection, and the second map prepared by the Service only if the results are unsatisfactory.

As a first step in the EAR process, the Service should continue with an assessment of the possible animal species in the study area, as well as vegetation mapping, using the small-scale color infrared, and should be concerned with the delineation of major vegetation associations as in the Notice of Intent review, as well as with the identification of any unusual features. Unusual features may consist of small isolated occurrences of a vegetation association within more extensive associations, or members of a disjunct vegetation distribution which may be common in other areas. Examples: an isolated stand of trees in a brush association, a meadow in a forested area, areas which have had historical disturbance and are now going through some stage of natural revegetation, vegetation indicating greater available moisture in arid locales, etc.

Work on the identification of possible species in the region should continue, with a greater emphasis on the confirmation of their existence. There should always be a distillation of this list to those species which may be of concern to the Service. To confirm the fact that specific species are in the region, publications, reports, and other published information such as maps, etc., knowledgeable persons in state and other federal agencies, and local and university experts should be consulted. Confirmation will generally be at two levels: 1) the species does use a given particular habitat in the region, and 2) the species is known to use a given particular habitat at a known location. Examples: 1) the Peregrine falcon is known to be in the area and nests on cliffs, or 2) the Peregrine falcon is known to be in the area and nests on specific cliffs; 1) sage grouse are known to inhabit the sage brush areas of the region, and 2) it is known that particular strutting grounds are located in particular locales; or that 1) elk are known to use certain types of areas as wintering grounds and 2) specific areas are known elk wintering areas.

It should not be forgotten that species which may be found outside of the area of study may in part depend on some locale in the area of study, e.g., wide-ranging hawks or other predators, migratory routes of waterfowl or undulates. If such species are found to be of concern, the habitats important to them found within the area of study should be delineated.

By combining the list of screened species (those of concern and confirmed to be in the region) and the locations of the known habitats with the vegetation map, a map of the area of study and the surrounding region can be developed displaying first order areas of concern. First order areas of concern are those which have been identified through the above procedure and which represent the focal point of concern.

Also of importance is the identification of habitats and locations of species of concern outside of the area of study, which may be indirectly affected by activities within the area of study. This may include wildlife sanctuaries, unusual stream habitats, etc. Areas of this category should be located on either the area of study base map or the specially developed regional map.

If a given species is considered to be of sufficient importance, areas that may constitute potential or possible locations of occurrence may be delineated as sensitive areas. That is, a threatened or endangered species or a species of any other category, such as one with a restricted range, may be found in a particular location within a habitat but not in other similar habitats in the area of study. In this case, it may be valid to assign the potential habitats the same level of concern or importance as those locales in which the particular species of concern is known to be located. To extend a previous example: if a Peregrine falcon is located on a given cliff and this area is delineated as a sensitive area, other cliffs of a similar character within the area of study may also receive such delineation.

At this point, areas of first order sensitivity have been delineated on the base map. They will include: 1) the known locations of habitats used by species of concern, and 2) areas of potential habitat of some species of concern.

The second major step in the EAR process is the assimilation of outside information into the process, so that some determination of appropriate development controls can be applied to the area of study. In many cases, it may be found that the protection of the habitats of concern will require the protection of land areas remote from or adjacent to the specific delineated habitat. These areas will be termed second order areas of concern. As they provide a maintenance function to first order areas, they should be given equal consideration.

Movement of water through the area of study and into the surrounding region may constitute an important transport route of impacts to areas other than those on which the activity occurred. For this reason, it is important that an appropriate understanding of the hydrologic system be developed. The Service should develop a map which displays the surface hydrologic features and includes perennial and ephemeral streams, ponds, lakes, springs, and seeps. Although this data map may be available through the surface management agency, vegetation may indicate features such as springs, seeps, and high water tables which may have been overlooked. This data is, of course, particularly important when aquatic or water-dependent habitats have been delineated as sensitive.

Other important elements will be geologic and soils information. Important information parameters are surface stability (and thus erosion potential) and hydrologic characteristics such as infiltration capabilities; aquifer potential of geologic formations should be requested from the surface management agency and the USGS. To be useful, the information should be in narrative form, with the important features displayed on a map as well.

An additional important outside information source is the pilot projects conducted by the Service. The pilot projects are designed to result in three major products. The first is a systems understanding of landscape units which can be applied to a set of KGRAs with similar characteristics. The second is some understanding of how geothermal resource development may alter those systems. The third is a set of specific activities-impacts which may be expected from geothermal activities on specific fish and wildlife.

These sources and others, such as published research, can be used to select second order sensitive areas. A variety of examples are presented in the following paragraphs.

1. In a perennial stream flowing out of the KGRA, there may be fish of an unusual species or of significant recreational value. Using published reports on this species, or if possible, using a pilot project study, an assessment of the species' requirements should be made. This is not seen as a highly detailed analysis, but rather one which may result in broad determinations, such as that clean gravel beds are required for spawning, low suspended sediment load is required for feeding, and certain temperature limits are required for proper body metabolism.

It is recognized that many other parameters of the species habitat may be very important; however, the fish and wildlife element of the EAR, by limitations of time and resources, cannot be a complete ecological study of each fish or wildlife species and its habitats.

After the parameters of the habitat have been screened and some selected as important, pilot project studies should be consulted. If suspended sediment load is considered to be important, the pilot project which most resembles the area of study should be assessed to determine what in the given hydrological system may control this parameter. Due to past depositional regimes, considerable potential sediment load may be tied up in the riparian areas, and thus special provisions should be made, or if the species of concern is of major importance, or restricted in distribution, or the area has a high erosion potential, activities may be completely restricted along the streams. In other situations, the upstream riparian areas may not have significant erosion potential, but specific soils in the headwater areas may be highly erodible and sensitive to surface disturbance and vegetation removal.

Thus, although the fish species and its habitat was located outside of the area to be leased, specific elements within the area of study were identified as being important to the maintenance of that habitat. Depending on the relative assigned value of the species, specific sections of the area of study may carry conditional use stipulations to ensure erosion potential. These specific areas may be completely restricted, and if the species is important enough and the potential risk great enough, the entire watershed contributing to that habitat may be restricted from geothermal activity.

2. Peregrine falcons may have been found to be using two or three cliff areas for nesting within the KGRA. It is likely that geothermal activity within a certain variable distance from those nesting sites may disturb the falcons to the point of making the cliffs undesirable for future nesting. Therefore, some semi-standard buffer zones should be established around the cliffs.

Using results of pilot project studies, special studies conducted by Service, and other published information, guideline standards should be developed by the Service. As new information is received, or the results of monitoring indicate needed changes, the guidelines may be updated. As an example, a standard may be that activity within one-half mile of the Peregrine falcon nest will disrupt nesting success. This

buffer should be modified in relation to the local topographic condition. If the nesting area is in a narrow valley or canyon, geothermal activity may be restricted one mile up and down the canyon and on the facing slope, but only restricted in an area one quarter mile from the nest across the topographic divide.

The fish and wildlife element of the EAR will result in a set of areas which have been found to have significant value, and a set of areas which will require withdrawal or special and restricted use to ensure maintenance of the significant areas. The areas recommended for withdrawal or lease stipulation should be delineated on the base map. The rationale for the delineation of the first and second order areas of concern, including the reasoning behind the evaluation of species of concern, should also be presented to the surface management agency.

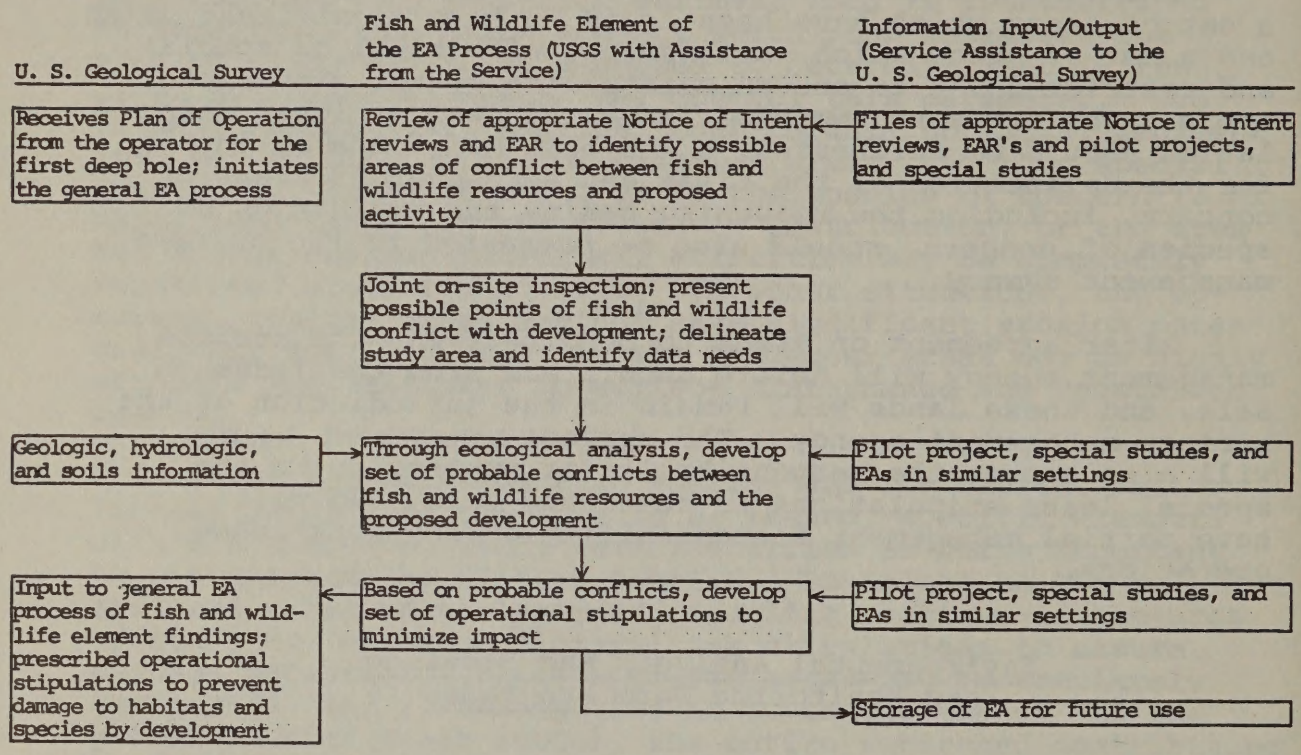
After agreement on areas to be withdrawn, the surface management agency will delete such areas from the lease sale, and these lands will remain in the jurisdiction of the surface management agency. The surface management agency will also assume the responsibility of putting forth the special lease stipulations in the lease sale, and will have partial management responsibility during post-lease operations.

Environmental Analysis and Baseline and Monitoring Data Programs

After the lease sale, at each stage of development, a Plan of Operation is submitted by the operator to the USGS. For each Plan of Operation, the USGS prepares an Environmental Analysis (EA) describing the ecological and environmental considerations of the proposed activities on the particular leasehold. If the Plan of Operation is for activities conducted before an Application for a Permit to Drill (APD) is filed, the EA effort is minor, and relies heavily on the surface management agency's EAR. With the first Plan of Operation covering a deep exploratory well, the USGS initiates a major EA effort. It entails information collection and analysis and involves input from interested federal, state and local agencies. Subsequent Plans of Operation covering activities occurring after the first deep exploratory well are once again minor efforts, with the first deep well EA being the information base.

Table 31

ENVIRONMENTAL ANALYSIS
FISH AND WILDLIFE ELEMENT



After the lease has been purchased, the operator may wish to carry out additional pre-deep well exploration. As this is analogous to the Notice of Intent level of pre-lease exploration, a Notice of Intent and a Plan of Operation is submitted to the USGS. The application will be forwarded to the Service and the surface management agency for review and for operational and rehabilitation recommendations. The Service should respond to this document as was recommended in the Notice of Intent review section.

The procedure may be modified due to the fact that an EAR and several Notice of Intent reviews on the area are likely to be part of the Service files. Based on the information and delineation produced by the fish and wildlife element of the EAR, the proposed exploration operations should be checked for their compatibility with the areas which may have been delineated for withdrawal or special operational stipulations. If the proposed operations are to occur in areas which are under operational stipulations, the Plan of Operation should be in conformance with those stipulations. If it is determined that it is not, recommended changes should be issued by the Service so that the operator will consider the possible problems identified by the Service during EAR development. Examples may be similar to those mentioned in the Notice of Intent review section; location and timing should be such that they would reduce possible impact on species and habitats. Operation and rehabilitation requirements should be applied as in the Notice of Intent review.

As the operator acquires knowledge of the geothermal resources, he may decide to drill a deep exploratory well. The operator will submit both an APD and a Plan of Operation to the USGS, and at this time the USGS initiates its major EA effort. The EA is an environmental analysis of the leasehold and an assessment of possible ecological environmental and socio-economic impacts of the proposed project. This level of environmental assessment allows the fish and wildlife element to 1) use ecosystems analysis in assessing the impact of the proposed activity on the biological systems of the leasehold, 2) to aid in the recommendations of operational stipulations, and 3) to provide a basis for recommending elements for the baseline data program.

Leaseholds are limited in size to reasonably compact units totaling not more than four square miles. Therefore the EA study can have a more ecological orientation than is allowed in the fish and wildlife element of either the Notice of Intent review or the EAR. This also means that the EA is not subject to the application of a specific set and sequences of assessment procedures, as is the case in previous assessment phases.

It should be remembered that during the EAR stage, areas which were delineated as inappropriate to geothermal development were withdrawn from the lease sale. Therefore, the leasehold to which the EA is to be applied will include those areas which were found to be sensitive to the degree of requiring lease stipulations, and those lands which were not found to be sensitive. All lands found to be highly sensitive were withdrawn from lease sale, and remain under the jurisdiction of the surface management agency. However, as noted above, the EA may include areas outside the lease, if they contain valuable resources which may be affected by geothermal activities.

Available information sources for this phase of environmental assessment should be pilot projects and special research projects conducted by the Service, and the Notice of Intent reviews and EAR which have been conducted in the area. Because of the ecosystems character of this assessment phase, the professional background and judgment of the field biologist is a major input. Professional judgment will have to be used in the application of information and the identification of possible conflicts between geothermal resource development and production and fish and wildlife resources.

The first step in the EA process is an optional site inspection conducted by the USGS, the surface management agency, the Service, local officials, and the operator. This inspection can be called for by any of the federal agencies, or possibly by local agencies concerned with the effects of geothermal development. At this meeting, points of possible conflict are discussed and the area of analysis is determined. Since this inspection is optional, it is important for the Service to make an early review of information on file and to identify areas of possible conflict. If there are reasonable grounds for concern, the USGS should be contacted so that an on-site inspection can be arranged.

Upon notification from the USGS that an APD has been received and that a major EA effort will be initiated, the Service should begin a review of the information in their files. This will include primarily the appropriate EAR and Notice of Intent review. This information should first be assessed for the location of biotic features in and around the leasehold which received area of concern status in previous assessment phases. Using information from pilot projects and special studies conducted by the Service, and background information on the general impacts expected to result from specific geothermal activities (Chapter 4, this volume), a quick assessment should be made on the likelihood of impact of delineated sensitive areas.

If it is determined by the Service that there is a potential impact on fish and wildlife resources, the USGS should be contacted as discussed above. At the on-site inspection, Service personnel should have a map which depicts that area of concern and at least an outline understanding of the possible threat to resources. At this time, some coordination of effort to address these concerns should be arranged. The USGS and the surface management agency should be aware of the possible information needs of the Service for continuation of the assessment, if the Service is to have a significant role in the fish and wildlife element. If not, the Service should make solid cooperative agreements on the role of its input to the USGS's fish and wildlife effort.

Further assessment of the probable impact on fish and wildlife resources must be made through the application of professional judgment and ecological understanding. Ecosystems understanding of the area of study requires the use of all available information appropriate to the systems on-site. These may include the ecosystems assessment of pilot projects of similar character, special Service studies on geothermal activities impact, and information derived in the EAR. If the Service is to conduct the fish and wildlife element, liberal use should be made of information in the form of data and interpretation from the USGS and the surface management agency. This not only will improve the fish and wildlife element, but will promote a more thorough EA effort on the part of the other agencies. The information requested will probably be of the same character as that requested in the EAR; however, here it should be more specific and provide a more detailed understanding of how the biological systems may depend on the existing physical systems.

By applying what is to be expected from geothermal development to what is known about the systems, the fish and wildlife element will result in a set of operational stipulations which will permit the development of geothermal resources while fish and wildlife resources may be protected. These stipulations may be in the form of altering operations through slight changes in well locations or roads, or in the form of special mitigating actions.

The completed EA will allow for the rational formulation of data elements for a baseline data program. This data program is designed to be carried out by the operator, and will assess environmental conditions before operations, as well as measure operation impacts. Currently regulations (30CFR;270.34) require that a baseline data program be conducted by the operator during the year prior to the submission of a plan of production. The information derived subsequent to the initiation of production, from the

monitoring data program, is used to detect possible effects of production on the ecosystem. As it is expected that much of the impact to fish and wildlife will occur during the construction phase, due to habitat loss and disturbance, it is necessary that the baseline data program be undertaken at an earlier stage of development. It is of course equally important that the baseline programs be scheduled at a point which does not induce unusual risk investment; therefore, the baseline program must be conducted when the operator is reasonably assured of future production, but before there has been excessive surface disturbance. An appropriate time may be a one-year period prior to the approval of a Plan of Operation and APD for the expansion of an exploratory well field from 4 wells to 5 or more.

Using all prior levels of assessment conducted on the particular tract, and transferable information from Service pilot projects and special studies, possible conflicts between fish and wildlife resources and geothermal activities should be identified. These points of potential conflict should formulate the basis of baseline data programs.

Since the range of possible environmental settings in the 13 western states is extreme, and the nature of the resource and method of utilization are so diverse, it is impossible to present here a specific set of data elements, much less collection methods and sampling schedules. The following is a set of possible data elements. Establish:

- Ground photo stations to record changes in vegetation associations.
- Line transects across ecotones and in specific vegetation associations.
- A study of the behavior and habits of local raptors and mammal predators.
- A series of benchmark streambed cross sections with photo stations to assess changes in erosion/deposition regimes.
- A longitudinal profile of streambed material with benchmark locations.
- A series of stations to assess the level of background noise.
- Seasonal color infrared aerial photography.

If there is an identified species of concern or a sensitive area, a set of specific and more intense baseline elements may be required:

- In the case of downstream habitats, the streams may be assessed for chemical constituents expected from geothermal activity, including increased surface disturbance. The streambed may be studied as above for possible changes in erosion/deposition regimes. The flow regime may be measured and correlated with precipitation measurements if the flow characteristics are considered important. The area delineated as a possible contributor to habitat degradation may be assessed through photo station and/or aerial photo analysis.
- If a raptor has been designated as a species of concern and an aerie located, it may be necessary to conduct a detailed assessment of noise levels at certain intervals from the nest site, and air quality sampling may also be carried out at appropriate elevations. In addition, behavioral studies may be conducted on individuals to determine their habits so that changes may be noted during monitoring.

A second major step in recommending a baseline data program is designating areas on the leasehold, but outside of the area to be developed, where a similar set of data elements may be conducted. This is designed to constitute a set of control measures against which to compare information received in the monitoring data program. Although yearly variations of natural conditions and animal populations can be great and the 1-year baseline data program is therefore scientifically inappropriate, some basic information and assessment of impacts can be made by the periodic comparison between the control and the activity areas.

The Service will receive copies of the monitoring data program at periodic intervals. The data should be compared against conditions before development, as represented by the baseline data program. If it is apparent that unacceptable impacts are occurring or are likely to occur, the Service should notify the USGS, and either recommend changes in the operation, or, if impacts are severe enough, cessation of the operations.

After the monitoring data program is ongoing, more development is expected on the leasehold. A Plan of Operation will be required as the resource is tested and additional construction is required to bring the area closer to production. Each time that a Plan of Operation is submitted, the USGS will conduct an EA to assess the impact of proposed activity. As each of these efforts relies heavily on the EA conducted at the first deep well stage of development,

the extent to which the Service may be involved will be limited. The Plan of Operation should be assessed for its compatibility with information on file, in particular the operation study. If at any stage of development a possible conflict is detected, notification should be issued to the USGS and arrangements made to resolve the issue.

CHAPTER 4

GEOTHERMAL ACTIVITIES AND IMPACTS

Part I - Environmental Setting

The characteristics of biological communities can be largely controlled by physical parameters at both the regional and specific site scale. Climatic conditions, which control timing and the degree of moisture available for plant growth, are themselves controlled by latitude and surrounding major topographic features. Recent and ancient geological occurrences have a bearing on surface and groundwater systems and their interactions. Hydrologic characteristics have, in turn, an influence on the occurrence of important micro habitats, represented by springs and seeps in arid regions and riparian habitat in wetter climates. Plant growth varies with physical conditions, and animal species distribution is influenced by both physical and vegetational variables.

Different portions of the western United States are characterized by specific sets of physical parameters which largely control not only the distribution and character of biotic communities, but the way impacts of a given geothermal activity may find expression in those communities. The geothermal areas delineated in the following maps have basic differences in geology and climate, resulting in differences in the dynamics of the hydrologic system, as well as differing soils and vegetation. Climatic, geologic, hydrologic, and edaphic conditions which promote high rates of primary productivity also create an ecosystem of high stability which is largely homogeneous; that is, without distinct habitat units. As environmental support systems become less favorable for net primary production, the spatial variation of micro climates, groundwater, and soils become significant in the establishment of distinct habitat units contributing to ecosystem stability. Animal species are not only dependent on the habitat with which they are usually identified, but often depend on other habitats for certain aspects of their life cycle. They also may depend on, or be depended upon, by other animals living in other habitats: in fragile ecosystems, unlike stable ecosystems in areas of high primary productivity, severe impact to a specific habitat unit can cause secondary and indirect impacts in other areas, and seriously alter the ecosystem.

A given set of geothermally-related activities, therefore, have the same direct impacts, such as vegetation removal, but the magnitude, and to some degree, the kind, of secondary and indirect impacts may not be similar. In studying the effects of geothermal development on fish and wildlife, the landscape

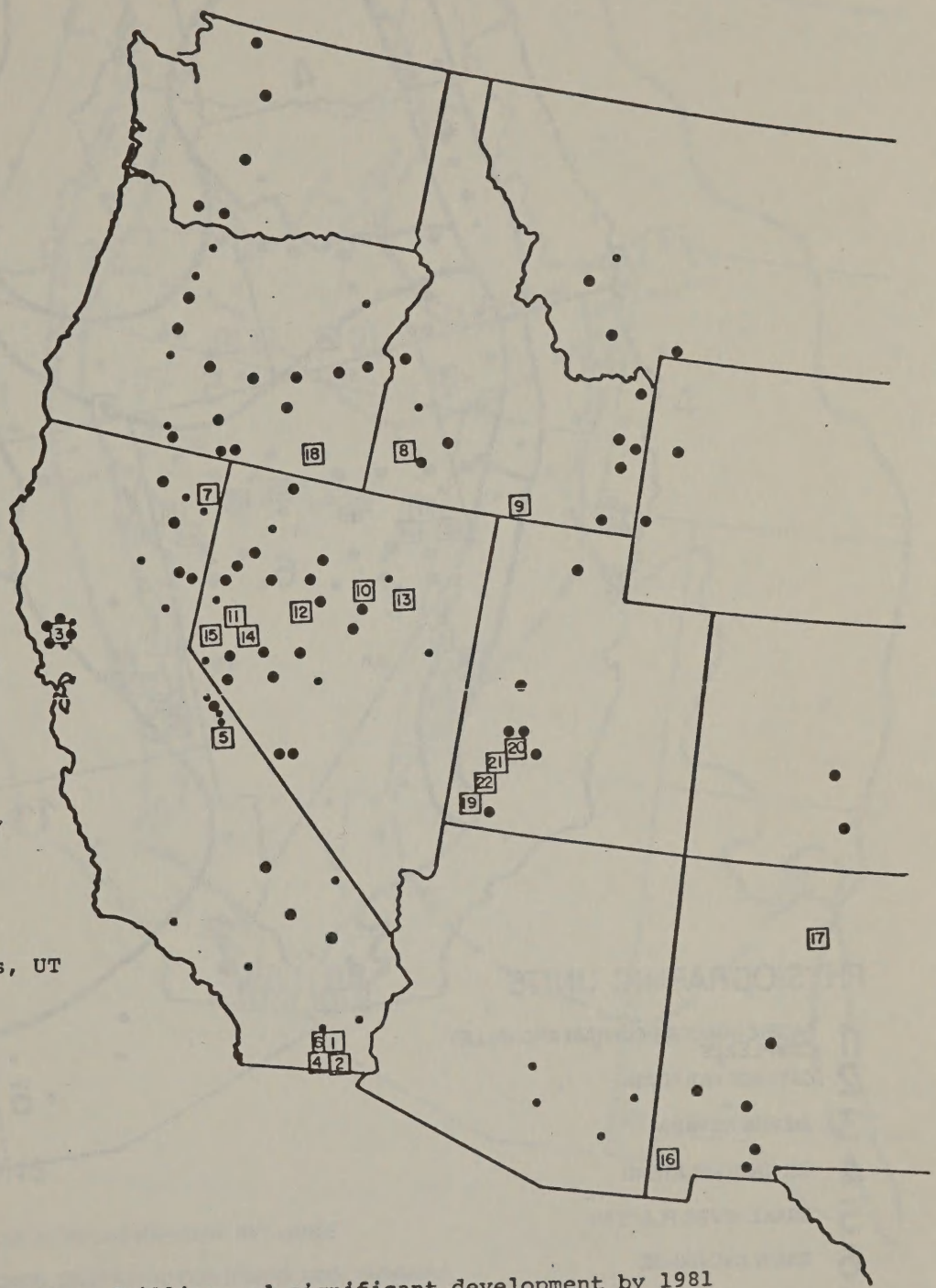
should not be considered as a random assortment of physical and biological parts, but rather as elements with characteristic modes of interaction and response, a network of influences.

Although the western United States displays an extensive array of bio-physical characteristics, near-future geothermal activity will occur primarily in three major physiographic units: the Basin and Range, the Snake River Plateau, and the Cascade Mountains. In the following maps and tables, the physiographic units are a primary parameter for the differentiation of Known Geothermal Resource Areas into sets likely to have bio-physical similarities. Much is known about the many physical and biological elements of these physiographic units; however, only rarely have those elements been brought together to provide understanding of the total set of interrelationships. Research could serve a valuable purpose in bringing these elements together into a systems study in each of the major units. This would offer the opportunity to develop a set of parameters, generalizations and stipulations which might apply to geothermal areas of the same character.

It should be kept in mind that the maps which follow are highly generalized so that the complexity of variety and pattern could be simplified to a usable scale. Before a judgment is made on the special characteristics of a given KGRA some additional inputs, in the form of field visits or study of previously published information, are needed.

Figure 22

GEOTHERMAL RESOURCES DEVELOPMENT



Areas of Significant
New Development by 1981

1 Brawley, CA
2 East Mesa, CA
3 The Geysers, CA
4 Heber, CA
5 Long Valley, CA
6 Niland, CA
7 Surprise Valley, CA
8 Grand View-Oreana, ID
9 Raft River, ID
10 Beowawe, NV
11 Brady-Hazen, NV
12 Dixie Valley, NV
13 Ruby Valley, NV
14 Soda Lake, NV
15 Steamboat Springs, NV
16 Animas Valley, NM
17 Valles Caldera, NM
18 Alvord Desert, OR
19 Beryl, UT
20 Cove Fort, UT
21 Roosevelt Hot Springs, UT
22 Thermo, UT

□ Areas with deep drilling and significant development by 1981 (numbers are for location purposes; do not indicate priority).

● Areas with significant surface exploration and deep drilling by 1985.

• Areas with current production, areas with past drilling and no current activity, and areas which have not had activity.

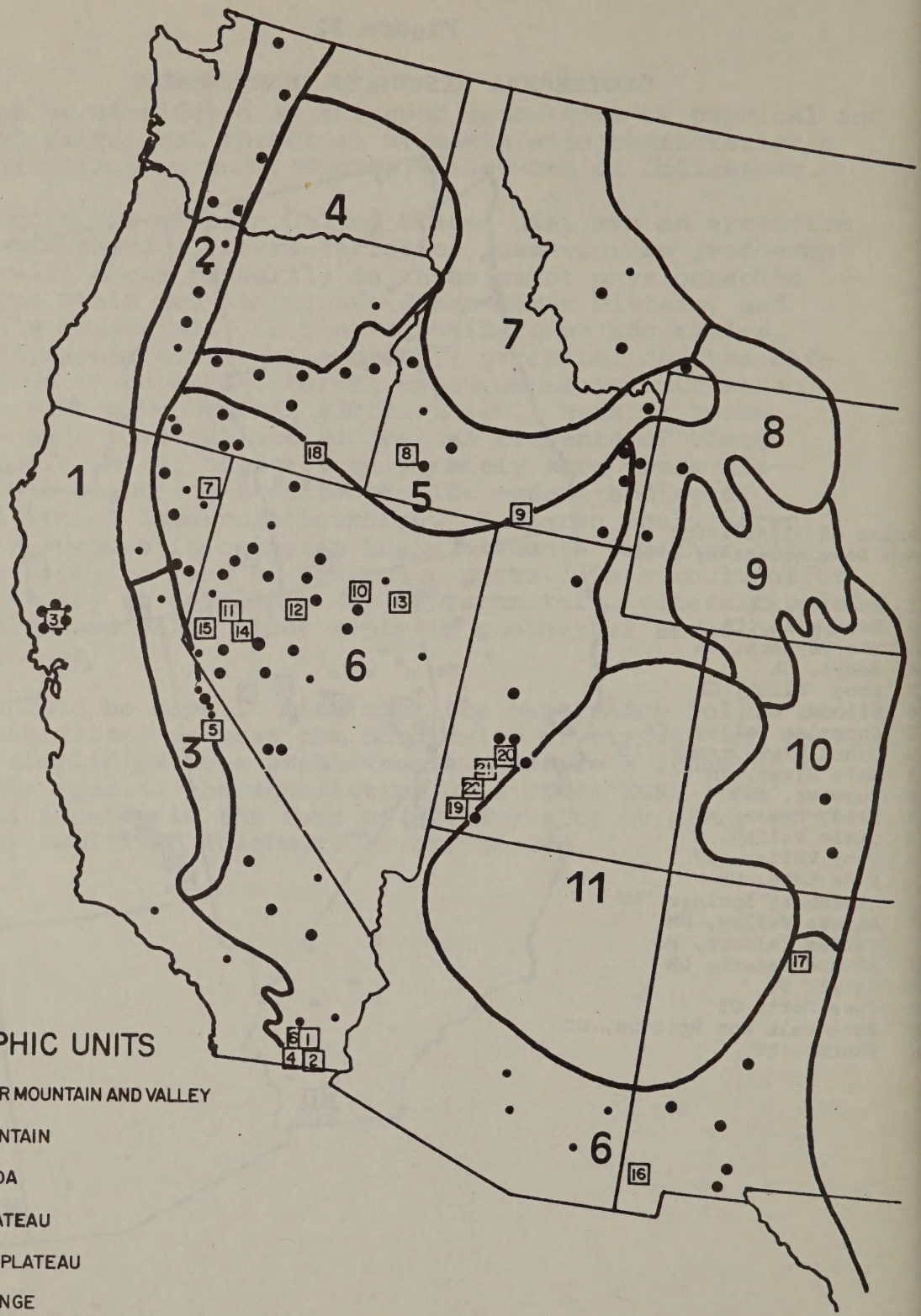
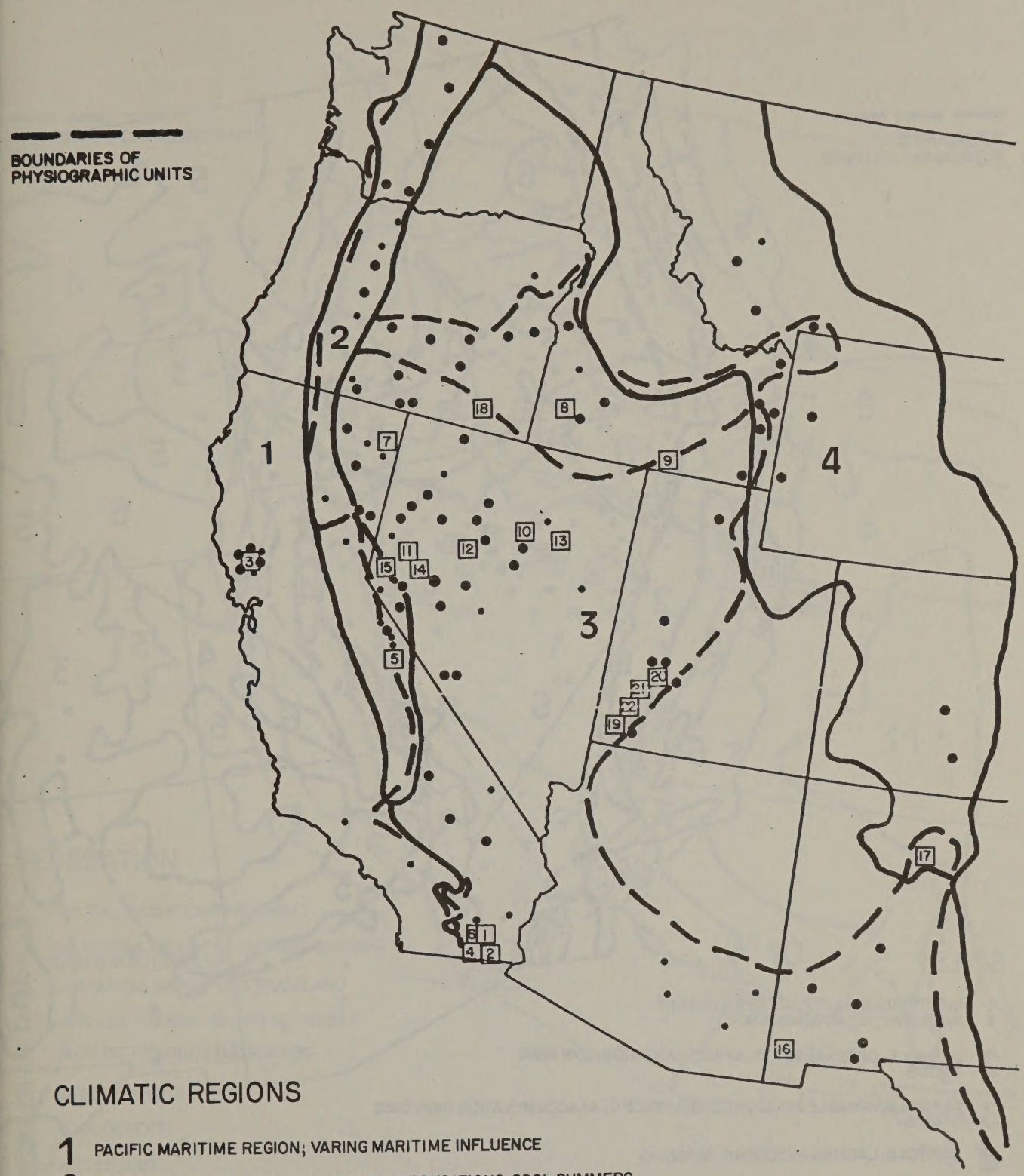


FIGURE 23 PHYSIOGRAPHIC UNITS
(SOURCE: ADAPTED FROM C.B. HUNT, 1967)



CLIMATIC REGIONS

1 PACIFIC MARITIME REGION; VARING MARITIME INFLUENCE

2 CASCADE-SIERRA REGION; ORGRAPHIC CONDITIONS, COOL SUMMERS

3 INTERMOUNTAIN PLATEAU AND BASINS; COLD TO WARM WINTERS, HOT, DRY SUMMERS, RAINSHADOW INFLUENCES

4 ROCKY MOUNTAIN REGION; COOL SUMMER AND COLD WINTER, INCREASED SUMMER PRECIPITATION

FIGURE 24 GENERALIZED CLIMATIC REGIONS
(SOURCE: ADAPTED FROM J. BALDWIN, 1973)

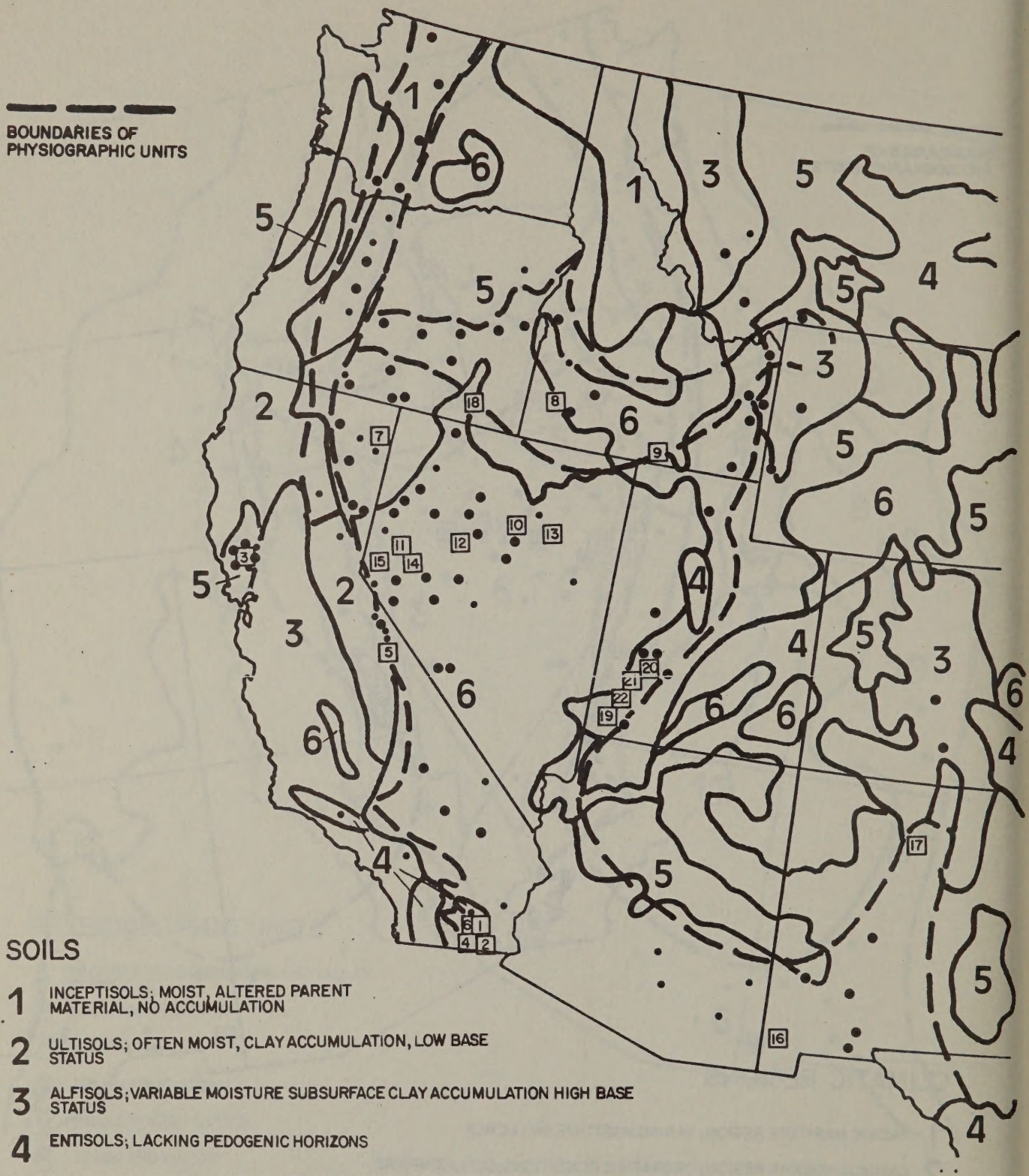


FIGURE 25 GENERALIZED SOILS BY ORDER (7th APPROXIMATION)
(SOURCE: 1967 SOIL MAP, U.S. ATLAS, U.S. SOIL CONSERVATION SERVICE)

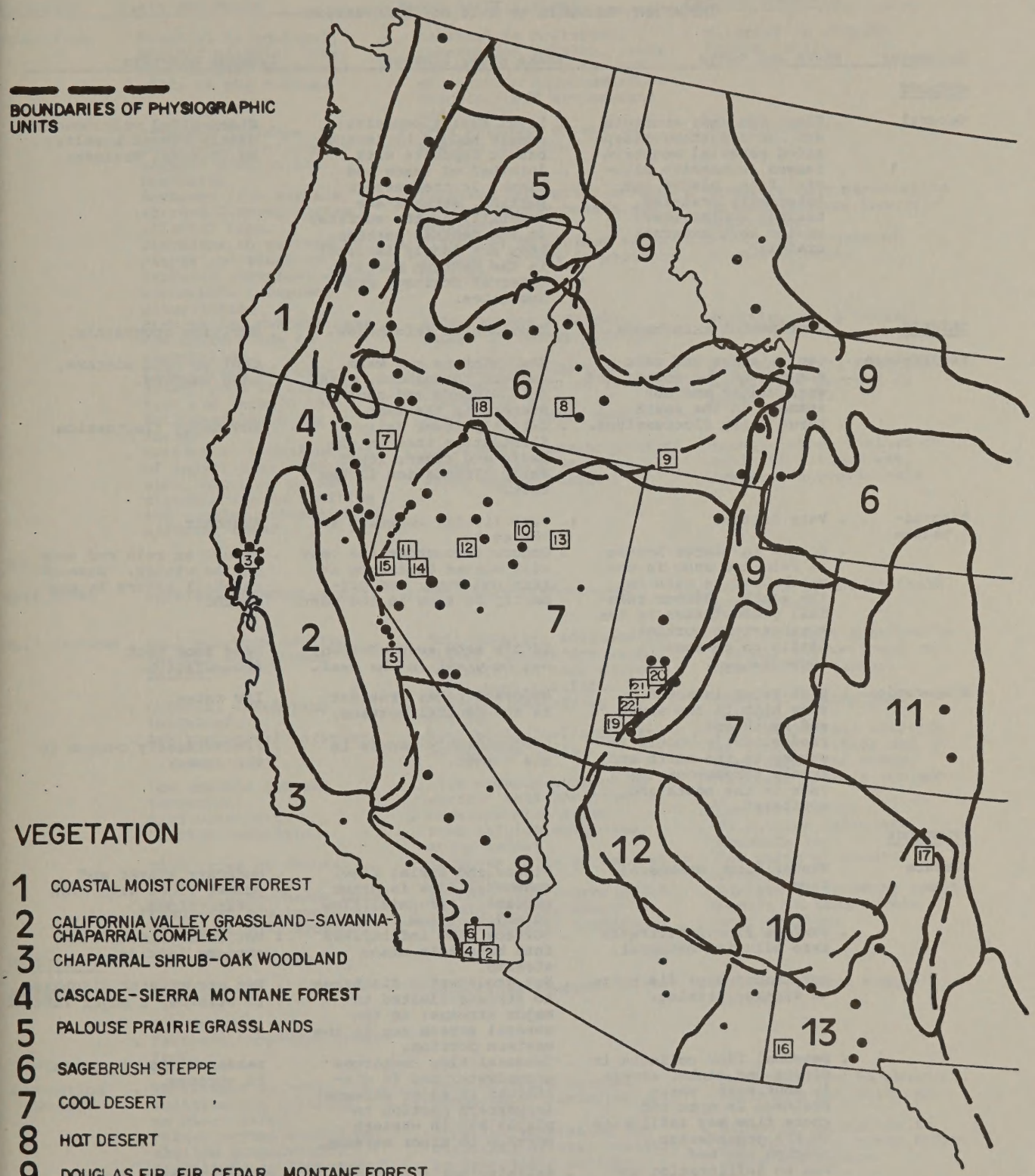


FIGURE 26 VEGETATION UNITS
(SOURCE: ADAPTED FROM A. KUCHLER 1964)

Table 32

IMPORTANT VARIABLES OF UNIT DIFFERENTIATION

Parameter	Basin and Range	Snake River Plateau	Cascade Mountain
GEOLOGY			
General	. Block faulted; mountain and basin system; steep-sided parallel mountain ranges, extensive alluvial fans, playas and internally draining basins; southeastern basins have external drainage.	. Level basalt deposits; deeply bedded horizontal basalt deposits with interbedded sands and clays; in the eastern portion, streams are generally on the surface; in the central portion, they are deeply incised; in the western portion, internal drainage predominates.	. Steep-sided volcanoes on gently sloped basalts; no internal drainage.
CLIMATE	. Continental rainshadow.	. Continental rainshadow.	. Maritime orographic.
Temperature	. Cool winters and warm summers in the north, and warm winter and hot summers in the south.	. Cool winters and warm summers throughout, with cold winters and cool summers in the east.	. Cool to cold winters, mild summers.
	. Large daily fluctuations.	. Slightly lower daily fluctuation than in the basin and river; lower daily fluctuation in the east.	. Low daily fluctuation.
Precipitation	. Very little.	. Very little, moderate in the east.	. Abundant.
	. Occurs in winter months as rain and snow in the north, and as rain in the south. Summer rainfall predominates in the southeastern portion.	. Occurs throughout the year with winter dominance as rain and snow, and primarily as snow in the east.	. Occurs as rain and snow in the winter. Summer rainfall occurs in the north.
	. Little to no snow accumulation.	. Little snow accumulation, may be great in the east.	. Deep snow pack accumulation.
Evaporation	. High rates in north, very high in the south and southeast.	. Moderate rates greatest in the central portion.	. Low rates.
	. Predominantly occurs in summer in the north and evenly throughout the year in the south and southeast.	. Predominantly occurs in the summer.	. Predominantly occurs in the summer.
HYDROLOGY			
Surface	. Winter flow, ephemeral flow.	. Winter and spring flow, ephemeral flow in minor streams. Perennial flow in major stream.	. Moderate winter and summer flows with high spring flows.
	. Surface flow infiltrates into alluvial material.	. Surface flow infiltrates into basalt in minor streams.	. Net infiltration from streams lacking.
	. Net groundwater discharge to streams lacking.	. Net groundwater discharge to streams limited to major streams; to the general stream net in the eastern portion.	. Net groundwater discharge to streams, a major factor.
	. Seasonal flow collects in playas and sinks, except in southeast, where drainage is open and where flow may infiltrate to the groundwater through the bed.	. Seasonal flow recharges groundwater and is discharged to major streams; in western portion to playas and in eastern portion to minor streams.	. Seasonal flow is contained in streams.
	. Due to infiltration and evaporation, salinity increases downstream.	. Salinity not a factor except in western portion.	.Salinity not a factor.

Parameter	Basin and Range	Snake River Plateau	Cascade Mountain
Subsurface	. Material is complexly braided alluvial fans, fine clastic sands and silts in the basins.	. Material is horizontal interbedded basalts, sands and muds, and in the eastern portion interbedded, breccia, tuff agglomerate, and basalt.	. Material is sloping bedded basalt.
	. Internal drainage, occasionally interconnected; open in the southeast.	. Open drainage except in western portion.	. Open drainage.
	. Recharge from surface streams flowing across alluvial fans.	. Recharge from minor streams flowing across basalt and sediments.	. Recharge from percolation of soil moisture from precipitation.
	. Discharge to surface at playas and sinks or isolated locations where streambeds intersect water table.	. Discharge to incised major streams, except in western portion.	. Discharge to general stream network.
	. High saline content near the surface due to evaporation.	. Salinity not a factor, except in western portion.	. Salinity not a factor.
	. Flow occurs in buried gravel beds in alluvial fans and through the full profile in the basins.	. Flow occurs freely in horizontal beds of fracture basalt and sands and perched on buried muds.	. Flow occurs in fractured basalt and perched on buried soils.
	. Horizontal translocation of impact over wide area, slow, somewhat unpredictable due to faulting and complex deposition in alluvial fans.	. Horizontal translocation of impact over wide areas, fast, unpredictable.	. Translocation limited to drainage basin, fast, somewhat unpredictable.
SOILS			
Soil order	. Aridisols predominate.	. Mollisols predominate.	. Inceptisols and Ultisols predominate.
Soil factors	. Soil moisture lacking through long summer season.	. Soil moisture adequate in winter, summer dry except for moisture near surface via summer rainfall.	. Soil moisture abundant in winter, intermittent dryness during summer.
	. Chemical weathering inhibited.	. Chemical weathering reduced.	. Chemical weathering active.
	. Low biological activity.	. High biological activity in surface soils.	. High biological activity in surface litter and in deep zones via roots.
	. Low organic content throughout.	. High organic content in surface soil horizons.	. Moderate organic content.
	. High alkalinity.	. Moderate alkalinity.	. Low alkalinity.
	. Calcium carbonate.	. Some calcium carbonate accumulation.	. No calcium carbonate accumulation.
	. High rates of natural erosion.	. Moderate rates of natural erosion.	. Low rates of natural erosion.
	. Surface disturbance could result in low levels of increased soil erosion.	. Surface disturbance could result in moderately increased soil erosion.	. Surface disturbance could result in high levels of soil erosion.
VEGETATION			
Basic units	. Cold desert.	. Sage brush steppe.	. Cascade-Sierra mountain forest.
	. Hot desert.		
	. Southern temperate grassland.		
Vegetation factors	. Variations in soil moisture are critical to plant life.	. Soil moisture is more dependable, variation not as critical.	. Soil moisture is abundant, variation not critical.
	. Phreatophytes depend on shallow groundwater, constitute an important habitat, minor changes may be critical.	. Riparian vegetation can withstand greater variation in hydrologic regimes.	. Riparian vegetation is unaffected by minor hydrologic alteration.
	. Nutrients cycle at soil surface via nitrogen-fixing algae, lichens, and mosses, and cycle throughout the active zone via deep-rooted plants and clay colloids.	. Nutrients cycle in the upper soil layers between organic and clay colloids, roots of grasses and the soil fauna.	. Nutrients cycle from colloids of the deep root zone to the plants, to the fauna of the litter layer, and through percolation to the deep root zone.
	. Vegetation is not important in preventing soil erosion.	. Vegetation is relatively important in preventing soil erosion.	. Vegetation is very important in preventing soil erosion.

GLOSSARY

ALLUVIAL FAN - A cone-shaped deposit of sediments from a stream running onto level plain. The fans generally form when streams issue from mountains onto low lands.

BIOME - A broad natural biotic unit consisting of a distinctive combination of plants and animals in a fully developed community.

BIOTIC PYRAMID - The relationship between primary producers, at the base of the pyramid, and subsequent herbivores and carnivores. The pyramid represents the loss in biomass of each trophic level.

CARRYING CAPACITY - The maximum number that can be supported in a given habitat.

ECOLOGICAL - Relating to ecology; the study of the interactions between organisms and their environments.

ECOSYSTEM - A community and its environment treated together as a functional system of complementary relationships, and transfer and circulation of energy and matter.

EPHEMERAL FLOW - Surface runoff and intermittent streams which flow generally only during and immediately after rainfall or snowmelt.

ENVIRONMENT - A complex of climatic, soil, and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival.

EROSION - The wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep.

FLUVIAL - Of, or pertaining to, rivers; growing or living in streams or ponds; produced by river action.

FOOD CHAIN - The transfer of food energy from the source in plants through a series of organisms by repeated eating and being eaten.

FOOD WEB - The interlinked relationship between food chains dependent upon the feeding preference of different organisms.

GROUNDWATER - That portion of that total precipitation which at any particular time is either passing through or standing in the soil and the underlying strata, and is free to move under the influence of gravity.

HABITAT - The place where an organism lives.

LACUSTRINE DEPOSIT - Material deposited in lake water and later exposed either by lowering of the water level or by the elevation of the land.

LIMITING FACTOR - The essential material available in amounts most closely approaching the critical minimum.

NUTRIENT CYCLE - The movement of those elements and inorganic compounds that are essential to life.

PERMEABILITY - The ease with which gases, liquids or plant roots penetrate or pass through a bulk mass of soil or a layer of soil.

RAIN SHADOW - The region of diminished rainfall on the lee side of a mountain or range, where the rainfall is noticeably less than on the windward side.

RIPARIAN - Relating to or living on, or located on the bank of a natural watercourse.

SCARP - An escarpment, cliff, or steep slope of some extent along the margin of a plateau, mesa, or terrace.

SEDIMENT LOAD - The sediment carried in suspension by a stream.

SPECIES DIVERSITY - The relative abundance of various species within a community.

SOIL FERTILITY - The status of a soil with respect to its ability to supply the nutrients essential to plant growth.

Part II - Activities-Impacts-Mitigations

The activities attending geothermal resource development are presented here as development phases. These phases -- casual use, pre-lease exploration and full field development -- represent successive decisions of the operator as he develops better resource potential information, as well as successive steps in the federal decision-making process. As a development evolves, the level or intensity of activity is limited by federal regulations. Usually in any given phase all previous activities are still allowed, along with a set of more intensive activities. Following a discussion of general construction problems, there is a summary table of development chronology and then a discussion of each phase.

To identify impacts of geothermal development, impacts of each activity will be designated in these terms:

Off-site - May include quite remote areas downwind or downstream liable to be influenced by noise, noxious gases, lowered water quality, etc.

On-site -- Or close to the site of activities.

Long-term -- Generally refers to a period of over one year, or one complete growing cycle.

Short-term -- About one year or less in environments where climate and soil conditions generally promote rapid growth; usually one time and not continuous.

Chemical -- Chemical rather than physical, causing corrosion, poisoning, modification of soil or water chemistry, as distinguished from killing of aquatic life by hot water or destruction of vegetation by bulldozers.

Physical -- Rather than chemical, as defined.

Geothermal -- Resulting from activities essentially unique to or closely related to the geothermal resource *per se*; e.g., impacts resulting from the release of hot brines into the environment.

Nongeothermal -- General equipment use or operations; e.g., road building, vegetation removal, building construction, etc.

Direct -- Exerting an effect directly upon the organism or environmental element in question; e.g., bulldozer directly destroys vegetation.

Indirect -- Exerting an effect upon the organism or environmental element in question through more than one stage; e.g., bulldozer directly destroys vegetation, leaving raw, erodible soil which is washed away in rains; sediments enter a stream and cover spawning areas, inhibiting photosynthesis.

While activities are standard and predictable, their effects in different environments are not. The material presented here will serve as a general guide to the complex of considerations which must be anticipated, investigated, and provided for as geothermal leasing proceeds.

General Construction

Description

Construction is not specific to a particular phase. It includes road building; drill pads and mud sumps; foundations for buildings, pipelines, and other facilities; and parking lots and storage areas. There is vegetation clearance, followed by rough grading, cut and fill, soil compaction, final grading, and maintenance. These activities may occur in any phase except in casual use.

Impact. Alteration of bio-physical systems. Habitat will be disrupted, altered and destroyed. The most prominent impacts from vegetation and soil disturbance are:

1. Both Short and Long-Term Changes in Plant Species Cover. Physiographic changes (massive earth movement, compaction, soil erosion and alteration of sub-surface drainage patterns) may permanently decrease the area's capacity to support vegetation. Natural revegetation brings successional changes with profound effects on wildlife because of changes in plant abundance and species diversity.

2. Habitat Changes. Alteration of the habitat's physical structure and nutrient cycling can lead to shifts in faunal populations. Some species may be able to take advantage of increased vegetation variation because of created edge effects, while others may be lost by the removal of cover. Changes in the nutrient cycle may alter the rate of energy flow through the ecosystem and change the relationships among species.

3. Accelerated Erosion and Changes in Soil Temperature and Moisture. Soil erosion is a serious, long-term impact. Soil depth, fertility and structure are the most critical elements of site productivity. Erosion produces higher sediment loads in surface waters. During transport, sediment suspension interferes with the ability of fish to obtain

oxygen and locate food, and also decreases light penetration, smothers insects and affects temperature. Sediments may invade sensitive spawning areas and be deposited in lake beds behind dams and at the mouths of streams and rivers. There will be changes in nutrient cycling from increased aeration, exposure of deeper soils to evaporation and temperature changes markedly affecting microflora and fauna. Leached nutrients may be carried to the groundwater system or surface waters, creating algal blooms and depletion of dissolved oxygen. Nutrient transfer may have a beneficial effect in certain cases, but appropriate levels would be a matter of chance. Changes in erosion-sedimentation can result in either long or short-term increases in nutrient availability, leading to species shifts and forcing out species in marginal habitat.

Mitigation.

1. Planning. The most effective mitigation for vegetation and soil disturbance is proper site selection at the outset. Particularly important habitats should be classified as sensitive and placed off-limits to development by Notice of Intent, Lease, Plan of Operations, or Application for Permit to Drill stipulations. These can be assessed and monitored by periodic aerial photographs as well as ground inspections. Aerial photos taken during the casual phase of development can show the most advantageous places for roads, such as natural breaks in vegetation along crests and ridges. Such photos will also show surface water to be avoided. When precise locations are optional for the operator, the most favorable routes or sites can be pointed out. Future requirements should be considered in planning initial roads to make them useful later (either for geothermal development or otherwise) and avoid excessive road building.

Timing is important, to avoid weather which might increase impacts, and to avoid conflicts with important parts of life cycles. Limitations on equipment operation and scheduling should prevent interference with fawning, kidding, strutting, nesting, etc.

Since poor pad and road construction can significantly increase impacts, adequate standards should be observed.

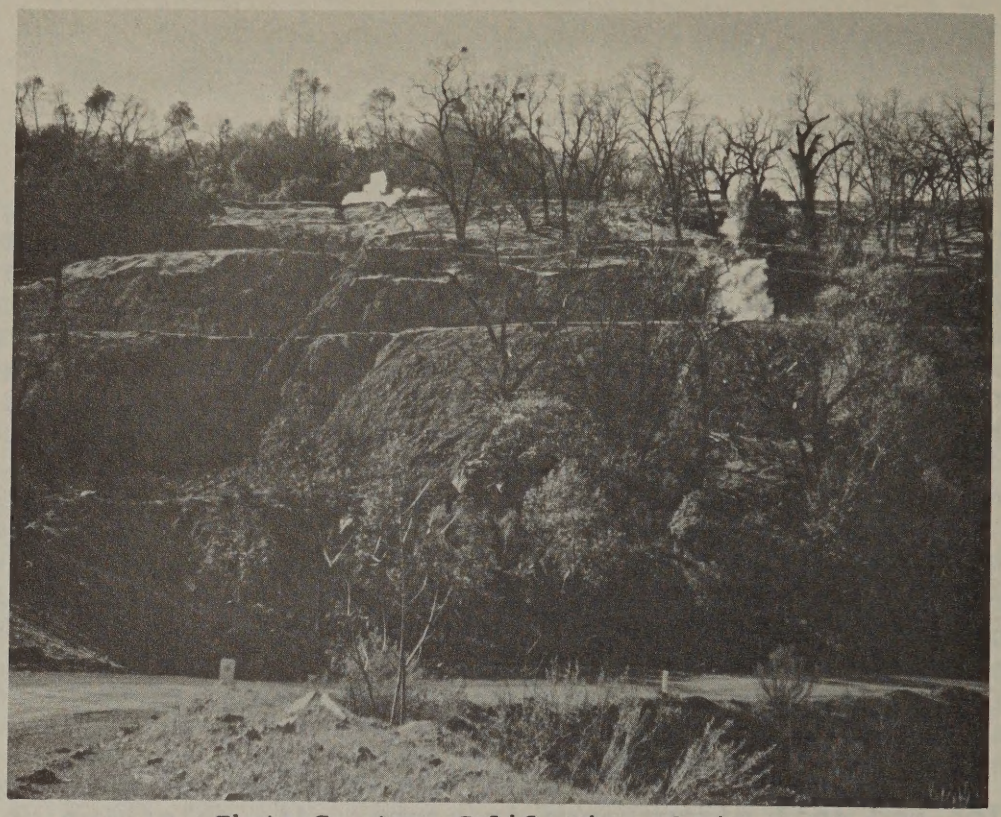


Photo Courtesy Calif. Div. of Mines and Geology

Rill erosion and slumping has occurred on these cut and fill slopes at some well sites at The Geysers, CA.

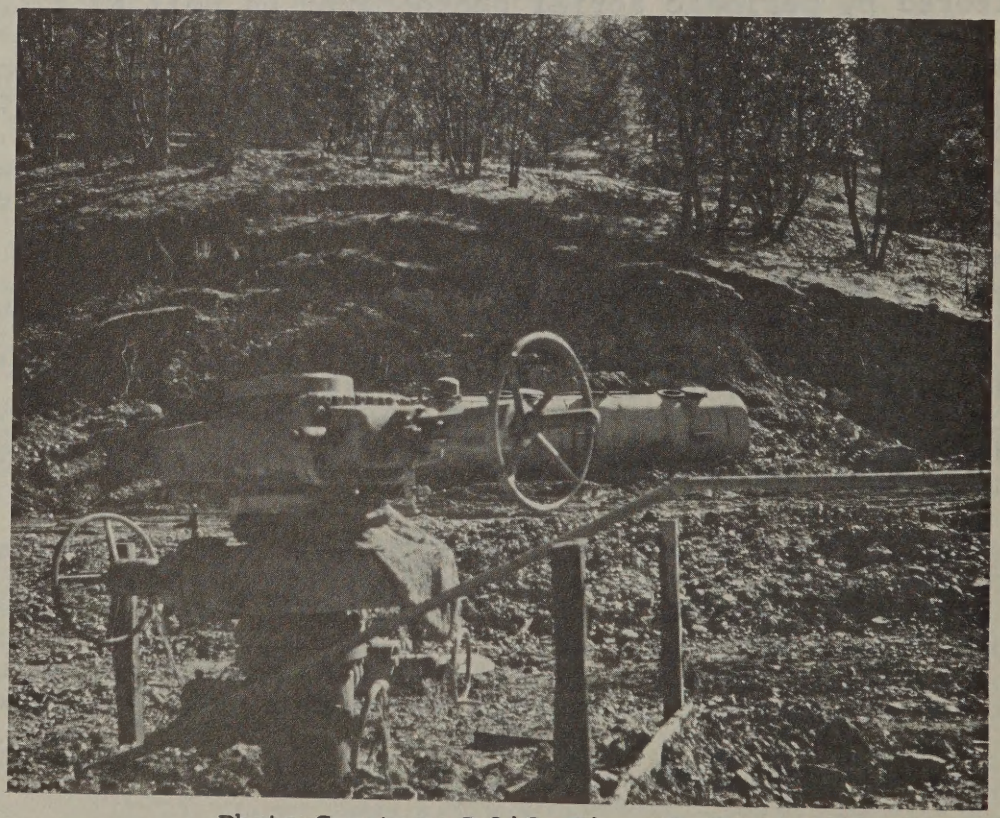


Photo Courtesy Calif. Div. of Mines and Geology

Slumping of cut bank at a well site at The Geysers, CA.

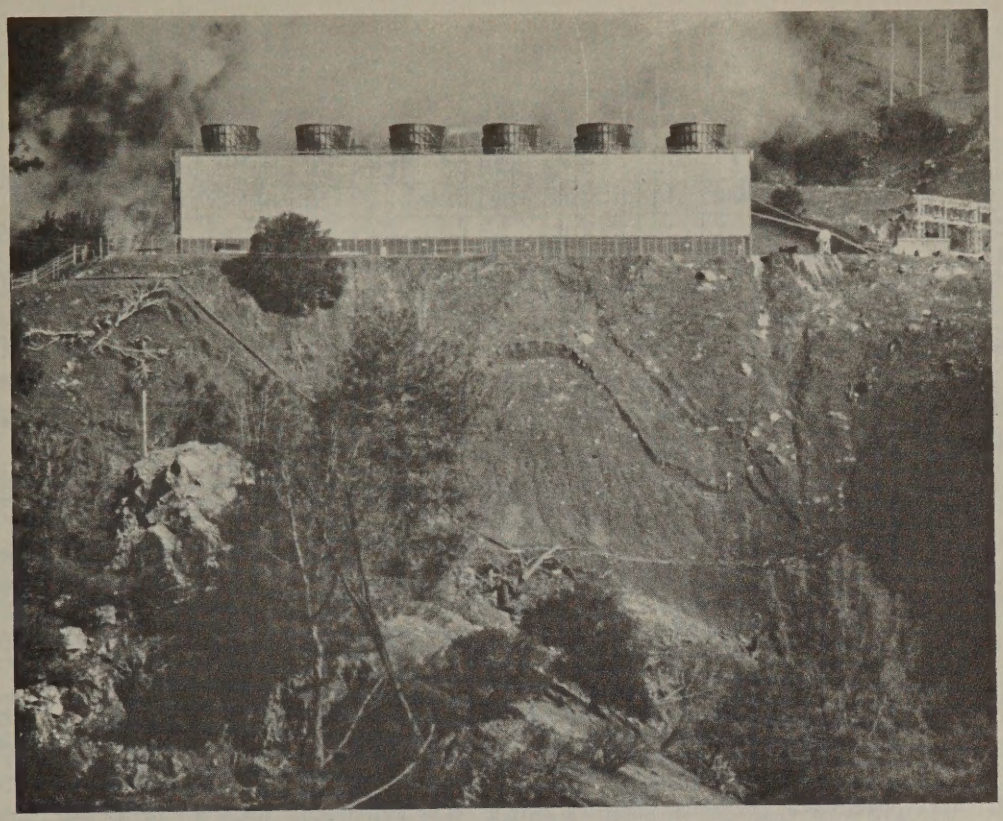


Photo Courtesy Calif. Div. of Mines and Geology

Slope movement in a fill slope at The Geysers, CA.

Photo Courtesy Calif. Div. of Mines and Geology

Drill sump contents were mixed with the nonengineered fill material to build the road, with slumping and erosion resulting from the instabilities of materials, The Geysers, CA.

2. Specifications. Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (U. S. Department of Transportation, 1974, FP-74) and Sections 9110 and 9111 of the Bureau of Land Management manual should be used as guidelines with case-by-case modifications of such specifications as:

- Cut slopes should be graded to a slope of 1.5:1 (horizontal:vertical) unless solid rock is encountered, in which case the slope may be left vertical.
- All fill material should be adequately compacted and graded to a slope of 1.5:1 or less.
- A berm a half meter high and a meter across at the base should be constructed around the outer perimeter of a drill pad.
- If there are signs of runoff channelization (development of gullies and rills), runoff should be collected in hard-surfaced drains, conducted to the bottom of the slope, run onto rock stilling wells or other energy dissipation devices to reduce erosive capacity, and dispersed along the slope as needed to allow percolation into the soil.
- All sloping, graded surfaces should be covered with rock or gravel unless included in a revegetation plan which precludes this type of surface treatment.
- Newly constructed road segments should be narrow (about 4.25 meters), one-way stretches with as few turnouts as possible.
- Where slopes are steep (greater than 5 percent), runoff should be channelized to the cutbank side of the road, conducted by culvert to an energy dissipator (bed of rocks, concrete box, etc.) at the foot of the fill slope, and spread by means of contour ditches into the native vegetation.

3. Terrain. Flat terrain should be considered for roads to diminish cut and fill. Slopes less than 5 percent usually present no special problems. Slopes between 5 and 15 percent present moderate problems. Slopes between 15 and 30 percent always present problems requiring slope stabilization and the disruption of energy in runoff waters. Slopes in excess of 30 percent should be avoided if at all possible.

4. Hydrology. Surface and shallow subsurface water flow characteristics should be identified and construction planned so it will not alter natural drainage patterns.

Part II - Activities-Impacts-Mitigations

The activities attending geothermal resource development are presented here as development phases. These phases -- casual use, pre-lease exploration and full field development -- represent successive decisions of the operator as he develops better resource potential information, as well as successive steps in the federal decision-making process. As a development evolves, the level or intensity of activity is limited by federal regulations. Usually in any given phase all previous activities are still allowed, along with a set of more intensive activities. Following a discussion of general construction problems, there is a summary table of development chronology and then a discussion of each phase.

To identify impacts of geothermal development, impacts of each activity will be designated in these terms:

Off-site - May include quite remote areas downwind or downstream liable to be influenced by noise, noxious gases, lowered water quality, etc.

On-site -- Or close to the site of activities.

Long-term -- Generally refers to a period of over one year, or one complete growing cycle.

Short-term -- About one year or less in environments where climate and soil conditions generally promote rapid growth; usually one time and not continuous.

Chemical -- Chemical rather than physical, causing corrosion, poisoning, modification of soil or water chemistry, as distinguished from killing of aquatic life by hot water or destruction of vegetation by bulldozers.

Physical -- Rather than chemical, as defined.

Geothermal -- Resulting from activities essentially unique to or closely related to the geothermal resource *per se*; e.g., impacts resulting from the release of hot brines into the environment.

Nongeothermal -- General equipment use or operations; e.g., road building, vegetation removal, building construction, etc.

Direct -- Exerting an effect directly upon the organism or environmental element in question; e.g., bulldozer directly destroys vegetation.

Indirect -- Exerting an effect upon the organism or environmental element in question through more than one stage; e.g., bulldozer directly destroys vegetation, leaving raw, erodible soil which is washed away in rains; sediments enter a stream and cover spawning areas, inhibiting photosynthesis.

While activities are standard and predictable, their effects in different environments are not. The material presented here will serve as a general guide to the complex of considerations which must be anticipated, investigated, and provided for as geothermal leasing proceeds.

General Construction

Description

Construction is not specific to a particular phase. It includes road building; drill pads and mud sumps; foundations for buildings, pipelines, and other facilities; and parking lots and storage areas. There is vegetation clearance, followed by rough grading, cut and fill, soil compaction, final grading, and maintenance. These activities may occur in any phase except in casual use.

Impact. Alteration of bio-physical systems. Habitat will be disrupted, altered and destroyed. The most prominent impacts from vegetation and soil disturbance are:

1. Both Short and Long-Term Changes in Plant Species Cover. Physiographic changes (massive earth movement, compaction, soil erosion and alteration of sub-surface drainage patterns) may permanently decrease the area's capacity to support vegetation. Natural revegetation brings successional changes with profound effects on wildlife because of changes in plant abundance and species diversity.

2. Habitat Changes. Alteration of the habitat's physical structure and nutrient cycling can lead to shifts in faunal populations. Some species may be able to take advantage of increased vegetation variation because of created edge effects, while others may be lost by the removal of cover. Changes in the nutrient cycle may alter the rate of energy flow through the ecosystem and change the relationships among species.

3. Accelerated Erosion and Changes in Soil Temperature and Moisture. Soil erosion is a serious, long-term impact. Soil depth, fertility and structure are the most critical elements of site productivity. Erosion produces higher sediment loads in surface waters. During transport, sediment suspension interferes with the ability of fish to obtain

5. Soils. Soil stability and depth in the lease area should be characterized. Unstable areas should be avoided, and, generally, efforts should be made to save topsoil where soils are deeper than 150 millimeters; local conditions will determine values in other cases. Saved topsoil can be piled at one side of the site during the first pass of the bulldozer or carryall and used for rehabilitation. If site resurfacing is not feasible or profitable, soil can be thinly spread elsewhere where it will provide benefits.

6. Vegetation. Vegetation characteristics should be identified and construction plans patterned to conserve the edge effect rather than eliminate it and to avoid critical or sensitive patches of vegetation. Attempts should be made to minimize soil and vegetation disturbance. In the past many construction activities have not considered the serious impacts of disturbance to the nutrient cycling system. Careful construction techniques can greatly decrease the area affected by the project. Equipment operators should be required to use a single route of approach to a destination, rather than indiscriminately driving over the landscape; material should be stored in selected central locations rather than in the nearest convenient space; turn-around areas and temporary parking lots should be selected at the outset and used consistently to avoid indiscriminate and unnecessarily widespread destruction of vegetation. Site inspection to appraise construction techniques is important.

Surface vegetation should be cleared so that the heavy brush can be utilized, if possible, in other areas, for habitat maintenance. Brush and other vegetation should not be burned off if means exist for removing it intact. Proper timing should be considered so that eventual replanting of stripped areas can make use of seasonal moisture. Fire breaks and wind reduction should be borne in mind. Revegetation programs must be instituted to hasten ultimate natural soil stability and should be carried out using appropriate plants, fertilizer, water, and cultivation. During natural revegetation, there will be a change in the mix of wildlife habitat, and thus a possibility of change in the wildlife mix.

Impact. Introduction of pollutants. Construction produces dust, exhaust fumes and noise, usually short-lived. Traffic on unsurfaced roads will generate dust, and wind on stripped surfaces may increase it. Dust can inhibit vegetative growth directly or through the modification of insect population balances favoring plant-eating insects. Under especially severe conditions, dust may become a significant source of sediment and suspended particulate material in surface waters.

Such conditions may exist where dirt roads parallel streams or lake shores and at stream crossings. Dust may be severe during drought and where soils have a high clay content. Both of these factors can be determined visually from climatological roads and from previous soil surveys. Usually, however, dust extends no more than 20-50 meters from the source.

Heavy construction equipment and associated support vehicles emit exhausts. The following table provides some basic figures for estimating emissions from diesel engines.

Diesel Truck Emission Factors

	Pounds/1,000 Gallons of Fuel	Pounds/Mile @ 5 mpg
Particulates	13	0.00265
SOx	27	0.00529
CO	225	0.0450
Hydrocarbons	37	0.0075
NOx	370	0.0750

Two pieces of heavy equipment working for five days and using 500 gallons of diesel fuel in the preparation of one drill pad would produce estimated total emissions of 6.5 pounds particulates, 13.5 pounds SOx, 112.5 pounds CO, 18.5 pounds hydrocarbons, and 185 pounds NOx, insignificant under most conditions.

Noise from construction equipment and traffic to and from a site will be audible at varying distances. Noise levels vary with humidity, vegetation type, topography, wind direction, etc. With respect to wildlife, the intensity of impacts is probably also related to the sensitivity of the affected species. Table 33 gives noise levels of related operations at the source; Table 34 gives correlation factors to be applied in estimating noise levels at various distances from the source. Higher noise levels in the area may affect the aural efficiency of such animals as owls, deer, rabbits, squirrels, etc., whose defense or hunting mechanisms depend largely on sound. Particularly sensitive types such as nesting raptors may also present unique situations (see also Deep Drilling).

Table 33

PREDICTED PROJECT-RELATED NOISE AT 50 FEET

Activity	Noise Level (dBA)[1] at 50 Feet
Road building equipment	80-90
Drilling rig (air)	102
Steam exiting a blooie with muffler	60
Steam well venting - standby	60 (at source)
Truck traffic bringing equipment and supplies	100

[1] Decibel A scale: A decibel is the universally adopted unit for measuring sound intensity. One decibel change in sound is approximately the smallest difference in sound intensity that the human ear can detect.

Source: Enviros, 1974.

Table 34

NOISE ATTENUATION BY DISTANCE ALONE (NO EFFECTS OF WIND, RELATIVE HUMIDITY, TOPOGRAPHY, ETC.)

50 ft. Base Level	1,000 ft. -26 dB	1/2 mile -34.5 dB	1 mile -40.5 dB	1-1/2 miles -44 dB	1-3/4 miles -45.3 dB	2 miles -46.5 dB	3 miles -50 dB
60 dB	34	25.5	19.5	16	14.7	13.5	10
70	44	35.5	29.5	26	24.7	23.5	20
80	54	45.5	39.5	36	34.7	33.5	30
85	59	50.5	44.5	41	39.7	38.5	35
90	64	55.5	49.5	46	44.7	43.5	40
95	69	60.5	54.5	51	49.7	48.5	45
100	74	65.5	59.5	56	54.7	53.5	50
105	79	70.5	64.5	61	59.7	58.5	55
110	84	75.5	69.5	66	64.7	63.5	60
115	89	80.5	74.5	71	69.7	68.5	65
125	99	90.5	84.5	81	79.7	78.5	75

$$\text{Sound Levels}_2 = \text{Sound Level}_1 - 20 \log \frac{(\text{distance}_2)}{(\text{distance}_1)}$$

+10 dB is normally perceived as being twice as loud. Adding two sounds of the same dB level produces a composite sound +3 dB above individual sound levels.

55 dB interferes with outdoor speech, etc.

70 dB is standard to protect against hearing damage from long-term exposure to noise.

Table 35

CHRONOLOGICAL ACCOUNT OF GEOTHERMAL ACTIVITIES AND IMPACTS

ACTIVITY	ENVIRONMENTAL CHANGE	IMPACT
Phase: Casual Use (no Notice of Intent Required)		
Presence of humans	Presence of humans	Disturbing to some forms of wildlife
Light vehicles	Noise Dust, with secondary increased stream sediment load	Wildlife disturbance Damage to plants, insects; (secondary) fish habitat damage
Aerial photography	Noise (aircraft)	Disturbing to wildlife
Water analysis	None	None
Crew bivouac	Use and alteration of vegetation/soil in bivouac Noise of camp operations Refuse accumulation	Damage to plants and soil structure Disturbance of wildlife Modification of nutrient cycling system
Phase: Pre-Lease Exploratory Operations (Notice of Intent Required, no Application for Permit to Drill)		
Geophysical operations		
Drilling of shallow temperature gradient wells	Road damage (heavy equipment) Dust, with secondary increased stream sediment load Noise Production of drilling wastes - piles of sludge Preparation of drilling area - soil disturbance and vegetation removal	Accelerated soil erosion; vegetation damage Damage to plants, insects; (secondary) fish habitat damage Wildlife disturbance Nutrient cycle modification; (secondary) vegetation/soil modification Soil/vegetation modification
ORV travel	Noise Dust, with secondary increased stream sediment load Vegetation crushing Soil disturbance	Wildlife disturbance Damage to plants, insects; (secondary) fish habitat damage Vegetation disturbance Soil disturbance
Explosives, seismic exploration	Dust, with secondary increased stream sediment load Noise Soil/vegetation disturbance	Damage to plants, insects; (secondary) fish habitat damage Wildlife disturbance Soil/vegetation disturbance
Camping and housing requirements of personnel	Use and alteration of vegetation/soil in bivouac Noise of camp operations Refuse accumulation	Damage to plants and soil structure Disturbance of wildlife Modification of nutrient cycling system
Phase: Post-Lease Exploratory Operation (Plan of Operations Required, Application for Permit to Drill Required for Deep Hole)		
Road building	Soil/vegetation disturbance Noise Dust, increased stream sedimentation	Damage to vegetation, insects and wildlife Wildlife disturbance Increased soil erosion; loss of habitat; loss of (secondary) fish habitat
Drilling pad construction	Soil/vegetation disturbance Increased soil erosion	Disturbance to soil/vegetation Damage to plants, insects; increased soil erosion
Sump construction and operation	Leakage of toxic materials: sump failure, overflow, leaching Soil/vegetation disturbance, dust	Vegetation/wildlife damage; groundwater pollution; nutrient system disturbance Damage to soil/vegetation; damage to insects, wildlife; increased soil erosion and stream sedimentation; loss of (secondary) fish habitat
Blooie lines	Noise Projection of particles (physical damage to vegetation/habitat)	Disturbing to wildlife Vegetation/habitat disturbance

ACTIVITY	ENVIRONMENTAL CHANGE	IMPACT
Deep exploratory drilling	Noise Road damage (heavy equipment) Fumes-exhaust and well fumes Soil/vegetation disturbance (clearing areas for storage, rocks, etc.)	Wildlife disturbance Accelerated soil erosion; vegetation damage Visual pollution; atmospheric modification Soil/vegetation disturbance
Housing of personnel	Soil/vegetation disturbance (clearing areas for storage, rocks, etc.) Creation of impervious surfaces Sewerage and solid waste disposal	Soil/vegetation disturbance Accelerated erosion where runoff leaves impervious surface Pollution: visual, water, groundwater; nutrient system disturbance, air pollution if burning
Transport of personnel, materials and equipment	Noise Dust, with secondary increased stream sediment load Road damage	Wildlife disturbance Damage to plants, insects; (secondary) fish habitat damage Accelerated soil erosion; vegetation damage
Temporary installation of facilities	Dust, noise, increased stream sedimentation Soil/vegetation disturbance (storage of materials) Creation of impervious surfaces	Damage to plants, insects; loss of (secondary) fish habitat Soil/vegetation disturbance Accelerated erosion where runoff leaves impervious surface
Blow-out risks	Discharge of effluent Noise Emergency procedures; soil/vegetation disturbance	Pollution: air, surface and groundwater, production of toxins, accelerated erosion Wildlife disturbance Soil/vegetation disturbance; modification of nutrient cycling system
Equipment maintenance (oil, gas, detergent)	Discharge of detergents, organic compounds (oil, gas, etc.)	Pollution of soil, water; vegetation destruction
Well abandonment and dismantling	Heavy equipment; increase human presence Noise	Destruction of vegetation/soil disturbance Disturbance of wildlife
Drilling mud disposal	Exposure of environment to toxins: chromates, NaOH	Disturbance of nutrient systems; death of wildlife/vegetation/habitat destruction
Phase: Full Field Development (Plan of Operation and Application for Permit to Drill Required)		
Extensive systematic drilling		
Pad construction	Soil/vegetation disturbance Dust, with secondary increased stream sedimentation Noise	Soil/vegetation disturbance; damage to plants, insects; accelerated soil erosion Local air pollution; loss of (secondary) fish habitat Wildlife disturbance
Storage of gear facilities	Soil/vegetation disturbance	Soil/vegetation disturbance
Transportation to sites	Road damage (and maintenance operations)	Accelerated soil erosion; vegetation damage
Road construction to new drill sites and supporting facilities	Soil/vegetation disturbance Increased sedimentation of surface water Dust, noise	Damage to plants, insects, wildlife; habitat disturbance, soil erosion Loss of (secondary) fish habitat Increased air pollution and wildlife disturbance
Pipelines from wells		
Movement of heavy equipment-transportation	Noise Dust, with secondary increased stream sediment load Road failure	Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage Accelerated soil erosion; vegetation damage

ACTIVITY	ENVIRONMENTAL CHANGE	IMPACT
Clearing lanes for pipes, etc.	Soil/vegetation disturbance Noise Dust, with secondary increased stream sediment load	Soil/vegetation disturbance; habitat modification, accelerated erosion Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage
Heavy equipment for trenching/ foundation operations	Soil/vegetation disturbance Noise Dust, with secondary increased stream sediment load	Soil/vegetation disturbance Disturbing to wildlife Damage to plants, insects; (secondary); fish habitat damage
Erection of above-surface pipelines	Barriers to migration Noise	Habitat disturbance; visual environmental modification Disturbing to wildlife
Road construction to and along pipeline lanes	Soil/vegetation disturbance; increased air pollution (dust) Noise	Damage to soil profile, plants; damage to insects, wildlife; loss of (secondary) fish habitat; increased soil erosion Disturbance to wildlife
Power generation facility (construction)		
Access roads	Soil/vegetation disturbance Noise, air pollution (dust)	Damage to plants, insects, wildlife; loss of habitat; increased soil erosion Disturbance to wildlife
Clearing of area	Soil/vegetation disturbance Noise Dust, with secondary increased stream sediment load	Soil/vegetation disturbance; habitat modification, accelerated erosion Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage
Temporary storage of equipment and construction material	Soil/vegetation disturbance	Soil/vegetation disturbance
Transmission lines		
Clearing lanes	Soil/vegetation disturbance Noise Dust, with secondary increased stream sediment load	Soil/vegetation disturbance; habitat modification, accelerated erosion Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage
Foundation construction	Soil/vegetation disturbance Noise Dust, with secondary increased stream sediment load	Soil/vegetation disturbance Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage
Access/maintenance roads	Soil/vegetation disturbance Increased air pollution (dust) with increased secondary stream sedimentation	Soil/vegetation damage, wildlife habitat loss; damage to plants, insects, wildlife Loss of (secondary) fish habitat; increased soil erosion
Equipment for laying lines	Noise Dust, with secondary increased stream sediment load Road failure	Disturbing to wildlife Damage to plants, insects; (secondary) fish habitat damage Accelerated soil erosion; vegetation damage

TIVITY	ENVIRONMENTAL CHANGE	IMPACT
erational activities related to othermal power production		
Thermal discharges	Increased atmospheric temperature Increased water temperature	Thermal modification Thermal modification
Condensate discharges	Increased air, water content	Fog and low clouds Lower light penetration Lower evaporation
Blow-out risks	Discharge of effluent Noise Emergency procedures; soil/vegetation disturbance	Pollution: air, surface and groundwater, production of toxins, accelerated erosion Wildlife disturbance Soil/vegetation disturbance; modification of nutrient cycling system
Reinjection	Lubrication of faults	Seismic activity; (secondary) landslides, soil slumps, damage to structures, well casings
Withdrawal of subsurface supportive matter	Lowering of surfaces with respect to sea levels; tilting of surfaces	Disrupts flows of seeps, springs, possible ponding; changes of drainage patterns; weakening foundations; damage to irrigation systems and roads
High mineral content water discharge	Water discharge to environment with increasing levels of salts and toxins	Modification of terrestrial and aquatic habitat; modification of nutrient cycling system
Maintenance activities		
Solid waste disposal (personnel, etc.)	Sewerage and solid waste accumulation	Pollution: visual, water, groundwater; nutrient system disturbance, air pollution if burning
Road maintenance	Noise, dust, soil/vegetation disturbance	Disturbance to wildlife; loss of plants, insects
Facility repair	Possible discharges through leaks Steam discharge when generators shut down Noise	Contamination of aquatic habitats Fog and low clouds Low light penetration Low evaporation Pollution of air, surface and groundwaters; production of toxins Disturbing to wildlife
Repair flood damage	Soil/vegetation disturbance Discharge of salts and toxins	Soil/vegetation disturbance Modification of terrestrial and aquatic habitat; modification of nutrient cycling system
Acid washings of "scaled" machinery	Discharge of salts and toxins	Modification of terrestrial and aquatic habitat; modification of nutrient cycling system
Solid waste disposal	Toxic elements discharge from the production of solid evaporites	Pollution to surface and groundwater from leaching of dump areas
Non-condensable gases and vapor discharge	Discharge of toxic substances to atmosphere	Modification of terrestrial and aquatic habitat; modification of nutrient cycling system; H_2S odors in atmosphere

Mitigation. Monitoring of dust can be done by site inspection of construction and road usage during the dry season. If excessive dirt is being generated, as evidenced by dust plumes and dust coverage of vegetation, it should be recommended to the Area Geothermal Supervisor that mitigation measures, such as oiling or watering, be required.

Exhause emissions will probably not have significant impacts on wildlife. If geothermal development is near urban areas, however, restrictions may be imposed by local air pollution control districts.

GRO Order #4 provides satisfactory guidance for noise control. It is possible, however, that special problems related to unique wildlife types may arise. These must be identified on a site-specific basis. Additional muffling techniques or alternative site selection may be required.

Geothermal Development

Phase: Casual Use

The Bureau of Land Management's (BLM) definition of "casual use" (Code of Federal Regulations [CFR], Title 43, 3209.0-5(d) is: "activities that involve practices which do not ordinarily lead to any appreciable disturbance or damage to lands, resources and improvements. For example, activities which do not involve the use of heavy equipment or explosives".

Activities of the casual use phase are: aerial photo surveys, geochemical and micro-gas surveys, stratigraphic, lithologic, and structural mapping. These may or may not demand the use of vehicles to move equipment. If vehicles are used, they are generally restricted to established roads and trails. For activities listed in the casual use phase no lease, operational permits or Notices of Intent are required.

Activity - Transport of Personnel and Field Gear in Light Vehicles

Description. Light vehicles (carryalls, sedans, pickup trucks) transport personnel over roads to observe geological formations, obtain rock samples, sample spring and stream waters, etc. Such activities are consistent with normal public access policies on public lands.

Type of Impact Expected

Off-site	___	On-site	X
Long-Term	___	Short-Term	X
Geothermal	___	Non-Geothermal	X
Chemical	___	Physical	X
Direct	X	Indirect	___

Impact. Light vehicles on existing roads and trails generate noise and dust. Wildlife may be disturbed, but such impacts are transitory. Some management areas do not have restricted off-road vehicle use, and unrestricted access could result in more serious damage. Off-road vehicle travel disturbs topsoil, upsetting the nutrient cycling process; damages or destroys vegetation; leaves ruts which channelize water runoff, leading to accelerated rates of soil erosion; and results in soil compaction. A Notice of Intent must be submitted to the surface management agency if there are off-road vehicle travel restrictions.

Mitigation. Regulations exist in many areas concerning the off-road use of vehicles. Travel should be confined to existing roads as much as possible. Off-road travel should follow a check of topography so ruts will not lead to erosion. Any ruts should be repaired promptly to avoid further cutting by water runoff. The operator should consult the surface management agency before extensive off-road travel to avoid disturbing important wildlife species during breeding or other important periods in their life cycles. This is not a regulation, but the operator should be encouraged to consult the appropriate agency or other biologists.

Activity - Aerial Photography/Remote Sensing

Description. Preliminary exploratory techniques include using low-flying aircraft for aerial, photography, infrared sensing, and geological observations.

Type of Impact Expected

Off-site	___	On-site	X
Long-Term	___	Short-Term	X
Geothermal	___	Non-Geothermal	X
Chemical	___	Physical	X
Direct	___	Indirect	X

Impact. No significant environmental impacts if species are not "buzzed" or harassed by low-flying aircraft.

Activity - Field Crew Bivouac

Description. Resource developers may establish campsites for their field crews, with bivouacs in one place for one or two weeks.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	x	Physical	x
Direct	x	Indirect	___

Impact. Impacts associated with camping are usually transitory and insignificant. However, if crews were large (8-10 individuals or more) and residence time of the camp was longer than two weeks, environmental problems could arise from inadequate camp sanitation procedures; concentrated vehicle parking and gear storage, resulting in vegetation destruction and soil compaction; and extended human disturbance of important watering areas and kidding/strutting/fawning/nesting grounds, preventing their use by wildlife.

Mitigation. Field crews and their camps should be organized and scheduled to preclude the use of areas during critical times such as waterfowl migration season, strutting, fawning, overwintering season, etc. Crews should place campsites and vehicle parking as close to existing roads as possible to minimize vegetation destruction and soil erosion. Campsites should be far enough away not to inhibit wildlife use of watering areas in arid regions. Camps should be far enough from surface water to prevent increased siltation or other impairment of water quality.

Phase: Exploratory Operations; Pre-Lease, Notice of Intent to Conduct Geothermal Resources Exploration Operations

After initial exploration, the operator may proceed to more intensive exploration techniques which do not constitute normal use of public lands and which may impair land resources. Typical operations of this phase are several geophysical surveys, requiring many men to walk a grid network, or the placing of sensors and the drilling of shallow (<150 meters) temperature holes. A Notice of Intent must be submitted to the surface management agency.

Activity - Camping and Housing Requirements of Personnel

Description. A crew of 2-4 carries out geophysical and geochemical exploration, collecting samples of rock, soil, surface waters, etc., for analysis. Much work is done on maps. Drilling of temperature gradient wells takes a crew of 4-6 and lasts a week to 10 days. If lodging is not available 20-50 miles away, a bivouac will be necessary. Bivouacs require tents or camper vehicles, meal cooking, garbage and trash disposal, and sanitation facilities.

Type of Impact Expected

Off-site	___	On-site	X
Long-Term	___	Short-Term	X
Geothermal	___	Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	___

Impact. Some wildlife may be frightened away, while jays, squirrels, porcupines, rats, etc., may be attracted. There will be limited soil disturbance, crushing of vegetation, cutting of branches or gathering of fallen wood for fires. Litter and garbage may be scattered about if camp operations are not well organized. The chance for wildfire is increased.

Mitigation. Camp sanitation should be planned in advance. Sites should be chosen for minimal disturbance to vegetation and should not be in critical areas. For example, if exploratory operations are to take place near raptor areas, strutting grounds, etc., the bivouac should be located outside the critical areas. Where possible, campsites should be in areas of little vegetation; and in arid climates, campsites should respect riparian locations and be placed to prevent increased erosion and pollutants reaching surface streams. Wildlife use of watering areas should be considered. Adequate fire prevention plans should be made before entering any area. Camp operations should be planned to prevent litter and garbage from being scattered. When possible, all litter and garbage should be removed daily, or kept in one place and removed when work is finished. Self-contained chemical toilets should be used, and the tanks later discharged into appropriate facilities in nearby towns.

Activity - Geochemical/Geophysical ORV Travel

Description. Limited cross-country travel in jeeps or other off-road vehicles (ORV), carrying crews of 1-4 with limited gear such as pH kits, hand-held temperature and ion probes, sample bottles for spring water, etc.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	___	Physical	x
Direct	x	Indirect	___

Impact. The impacts of ORV travel are becoming a serious problem with heavy recreational use in many remote areas. When exploration is added to present recreation use, there may be significant impacts in heavy-use areas. ORV travel causes direct stream sedimentation during stream crossing; disturbs the soil surface through tire rutting, gullying on steep slopes, wheel holes, and ditches in moist habitats; crushes and destroys vegetation; introduces noise into otherwise quiet areas; and causes soil compaction.

Mitigation. Exploration routes should be planned in advance using topographic maps. Destinations should be marked and routes chosen for shortest total distances and most moderate terrains. Photographs taken during aerial reconnaissance can be used to pinpint routes; i.e., dry river beds may serve, and decrease possible vegetation damage. Existing roads and fire trails should be utilized. Any natural vegetation break, such as ridge lines and crests, should be used to limit soil disturbance. Potential erosion could be reduced by limiting ORV use along stream course edges and in areas of ephemeral surface flow.

Activity - Geothermal/Geophysical, Blasting (Dynamite or Other Explosives)

Description. Explosive charges are sometimes used to analyze subsurface geological formations.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	___	Physical	x
Direct	x	Indirect	___

Impact. Very little surface noise or physical disturbance results. If used on land and not near water, there should be no significant effect upon fish or wildlife, except if conducted in areas used by wildlife during breeding or other important periods in the life cycle.

Mitigation. Avoid blasting in marshes, near open bodies of water or in sensitive habitat areas.

Activity - Geophysical/Geochemical - Drilling of Shallow Temperature Gradient Wells

Description. Measuring the increase in temperature per unit of increasing depth yields indications of the location of exploitable geothermal resources. A small hole, no more than 4 inches in diameter is drilled to a depth of no more than 150 meters, and the temperature measured at short intervals.

Type of Impact Expected

Off-site	___	On-site	X
Long-Term	___	Short-Term	X
Geothermal	___	Non-Geothermal	X
Chemical	___	Physical	X
Direct	X	Indirect	X

Impact. The impact of temperature gradient drilling is only slightly greater than in ground reconnaissance. Generally no site preparation is necessary. The rotary or impact drill rig is a mobile single-unit vehicle, powered by a gasoline or diesel engine. The operation lasts for several days, during which there may be increased traffic of commuting workers and service vehicles. There are limited amounts of noise and dust. The most important impacts may involve soil compaction and vegetation destruction resulting from the placement of the rig. Between .8 and 1.6 cubic meters of drill cuttings are often left on the site. Since cuttings are usually low in fertility and do not support vegetation, they present a local problem of visual scars. There will be minor impacts from spills of gasoline and lubricating materials, litter from the crew, parking of personnel vehicles, and other associated activities.

Mitigation. Test drilling sites should be located well away from surface water to prevent pollution from soil erosion or spills of gasoline or oil from the drilling operation. Well sites could be located on existing roads or in areas which are naturally clear of vegetation. Roads should be located and

constructed so that more roads will not be needed to bring in heavy equipment later. Drilling sites should be designed with a levee surrounding each pad to control runoff and prevent erosion and stream sedimentation. The height and width of these levees will vary with the slope of the terrain and amount of annual rainfall. Another method of preventing soil erosion and stream sedimentation is to channel runoff from drill pads into holding ponds, which would allow the water to dissipate its energy and slowly percolate into the soil and on into the water table. The permeability of the holding ponds may be varied in order to provide surface water for animal use in water-short areas. In most cases mufflers on the drill rig engine can reduce noise. Drill cuttings can be transported to a suitable dump site or spread on an adjacent roadway.

Phase: Exploratory Operations; Post-Lease, Application for Permit to Drill (APD)

After lease purchase, the operator is allowed to undertake more intensive exploration entailing deep drilling. Wells are currently drilled to depths of about 3,050 meters and involve large, highly-engineered drill sites. Operations usually consist of 1-5 deep wells for finding and testing geothermal fluids. The operator is required to submit a Plan of Operation and APD to the USGS.

Activity - Housing of Personnel

Description. A crew of from 20-24 runs round-the-clock drilling operations. If drill sites are near towns, accommodations are normally there, but if drill locations are remote, accommodations will have to be provided on site. Sleeping and mess facilities are house trailers or tents.

Type of Impact Expected

Off-site	x	On-site	x
Long-Term		Short-Term	x
Geothermal		Non-Geothermal	x
Chemical	x	Physical	x
Direct	x	Indirect	x

Impact. Locations for house trailers or tents would have to be leveled, but disturbance would be minor except in areas of steep terrain.

If sanitation is sloppy and not carefully supervised, litter, garbage and possibly human wastes could accumulate, causing problems of odor, leaching of nutrients from the refuse, etc. The small number of persons would limit the seriousness of such impacts. However, the variety of pollution could result in significant impacts in sensitive locations.

Mitigation. Most problems can be prevented or avoided by proper sanitation. Solid wastes should be collected and trucked from the site to approved disposal areas. If this is not feasible, latrines should be built using approved techniques. Drain holes for bath and dishwashing wastewaters can be dug and filled with gravel. Personnel from the surface management agency responsible for the area (USFS or BLM) can be consulted about such facilities.

Activity - Road Construction

Description. Deep well drilling operations require heavy equipment (semi-trucks with cement, drill rig structures, etc.). Since existing roads often approach chosen sites within 1-1/2 to 3 kilometers, these may be improved. Since several exploratory wells are normally .4 to .8 kilometers apart, about 5 to 7 kilometers of new road is necessary for one exploratory effort of deep well drilling. Road improvement and construction use heavy equipment, such as a heavy bulldozer, a road grader, perhaps a carryall or front end loader and dump truck, soil compactors, a water truck, and occasional supporting equipment such as lubrication and gasoline trucks. These usually operate during daylight hours and produce limited quantities of noise and dust. On moderate slopes and most soil types, 1-1/2 kilometers of road can be constructed in 2-3 days.

Type of Impact Expected

Off-site	X	On-site	X
Long-Term	X	Short-Term	
Geothermal		Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	X

Impact. See General Construction section. The off-site areas where road construction materials are obtained may be affected. Gravel pit operations and earth moving may have effects upon fish and wildlife. These off-site areas should be evaluated.

Mitigation. See General Construction section. Where possible, road location should correlate with planned drill pads, so that several pads will be close to or on one road. If firebreaks have been constructed at an earlier phase, they should be incorporated into transportation routes.

Activity - Drilling Pad Construction

Description. Heavy-duty drilling operations use a level pad of about 1.25 hectares where the drill rig and associated equipment (generators, mud pumps, etc.) is set up. There must also be enough room for supply trucks to park and turn around. The land for each pad must be cleared, leveled and compacted. Heavy equipment is used to construct the pad and to build a levee around the pad as well as the mud sumps needed. Pad construction is limited during this phase, and usually only one hole is drilled. If it is not successful, however, a new area (perhaps 8 kilometers away) may be explored. If the leasehold is small and temperature gradient data are encouraging, another hole may be drilled within .40 kilometers. The developer may drill one or two more wells in order to adequately assess the resource potential. Each of the drilling operations will require a pad. Site preparations use several pieces of heavy equipment, probably two heavy-duty bulldozers, carryalls, a soil compactor, a water truck, a road grader and supporting lubrication and gasoline trucks. About 3-4 days are needed to prepare each site.

Type of Impact Expected

Off-site		On-site	x
Long-Term	x	Short-Term	x
Geothermal		Non-Geothermal	x
Chemical		Physical	x
Direct	x	Indirect	x

Impact. Since pads are large, General Construction impacts should be studied. Poor pad and road construction can increase sedimentation and silting.

Mitigation. See General Construction.

Activity - Sump Construction and Drilling Mud Disposal

Description. Near the drilling pad (within 91 meters) a mud sump must be constructed for the temporary storage of drilling muds and for possible temporary storage of geothermal resource effluent produced during short tests. Sumps generally

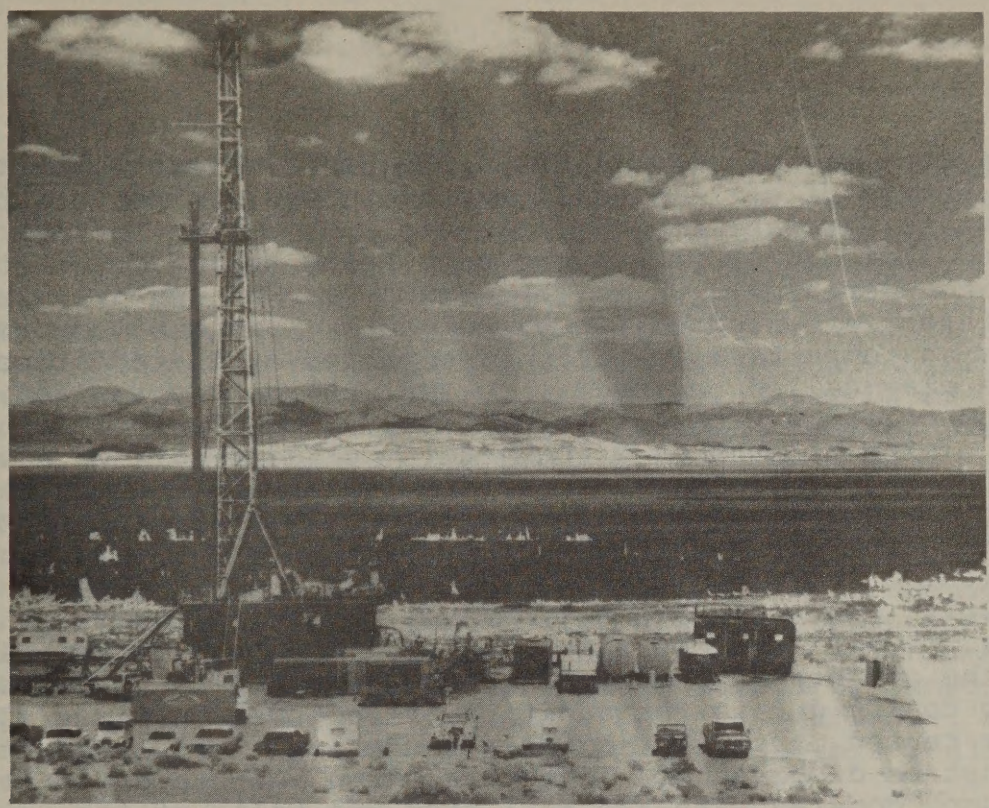


Photo Courtesy Calif. Div. of Oil and Gas

Small deep drilling pad at Mono Lake, CA.

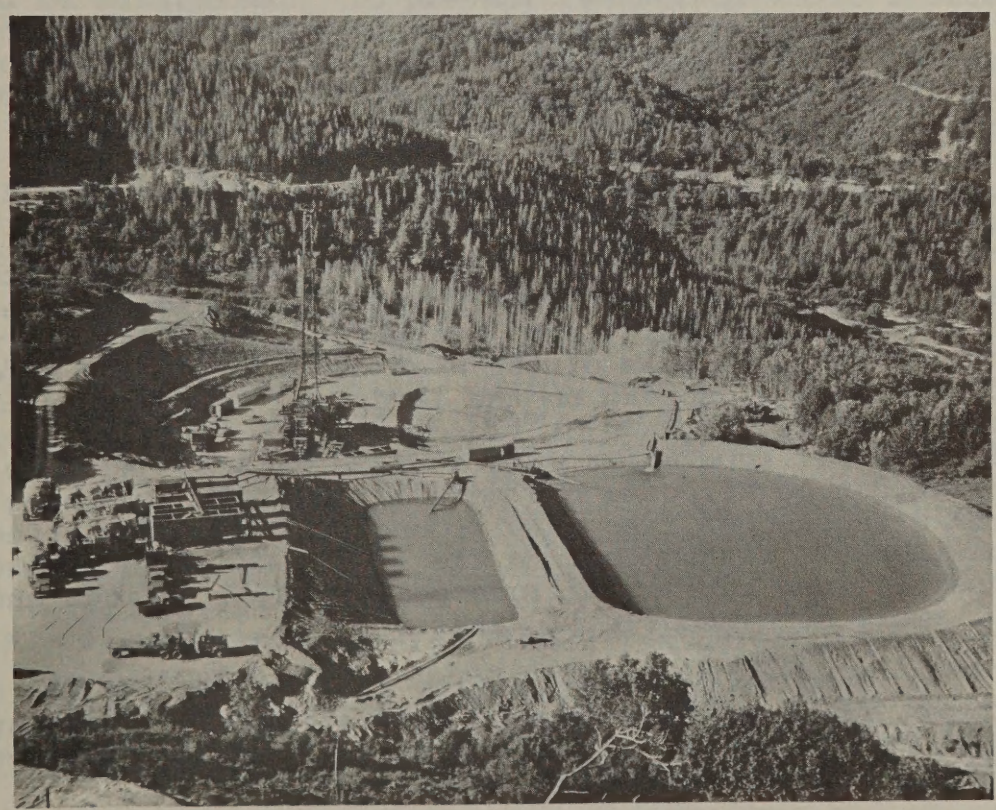


Photo Courtesy Calif. Div. of Oil and Gas

Large deep drilling pad at The Geysers, CA.

have a capacity of about 1,900-3,800 cubic meters. Due to the toxic nature of certain drill mud additives, sumps are normally subject to permeability requirements. Sump construction is limited during this phase, one sump being needed for each drilling operation. Up to three sumps may be required in an exploratory effort drilling three wells. Sumps often undergo extensive compaction, usually accompanied by the addition of a fine clay called bentonite, to seal the soil pores and reduce the sump floor and wall permeability. Sump construction uses heavy equipment such as 2 heavy-duty bulldozers, 1 or 2 carry-alls, a soil compactor, a front end loader and dump truck for bentonite spreading, a grader, and supporting lubrication and gasoline trucks.

Drill mud may contain additives which are toxic, or which during the drilling operation may pick up toxic contaminants from the geothermal resource. Muds are normally very basic (pH up to 10) due to the addition of sodium hydroxide. They may be reused, but after extensive use lose their properties and must be disposed of. They are often left to dry in the mud sump, covered with the soil from the walls of the sump, which is then graded over to an appropriate contour. Alternatively, muds may be loaded into a truck and disposed of at a dump site approved by the surface management agency or by local governmental agencies.

Type of Impact Expected

Off-site	X	On-site	X
Long-Term	X	Short-Term	X
Geothermal	X	Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	X

Impact. In addition to General Construction impacts, there is a danger of pollution, which would be extensive if a mud sump should fail. Under ordinary operations, the vegetation and small animals of the area may be directly affected by toxic materials spread on the landscape if concentrations of toxins are high. Rain or flooding could compound impacts by moving toxic substances into surface waters. Aquatic organisms can be affected and possibly killed. Leaching of the toxic substances into deep groundwater may have effects at considerable distances from the site. Resulting impacts are speculative, but may include pollution of springs and seeps, small streams or well waters.

A mud sump fails when capacity is exceeded and the sump overflows, or when it is damaged and releases its contents. Drilling muds, and any geothermal fluids from testing activities stored in the sump, flow downstream.

Mitigation. Unstable soils, landslides (either active or inactive), surface water drainage pathways, areas subject to flooding, and other types of high hazard locations should be identified and avoided for sump location. Steep topography is conducive to sump failure, due to higher downslope compaction requirements and drainage characteristics of steeper landscape surfaces. Unstable soil and underlying geological formations may tend to cause sump failures. Sump walls must be adequately compacted and strong enough to withstand minor earthquakes and moderate erosive forces of the weather.

The mud sumps should have an impervious lining to prevent infiltration of the contents into adjacent surface, subsurface or deep-lying groundwaters. In general, mud sumps should have adequate capacity for the wastes from drilling operations (drill cuttings and contaminated muds) and also have some capacity to handle geothermal fluids which may require temporary storage during drilling or testing. For most purposes, a sump with a capacity of from 1,900 to 3,000 cubic meters would be adequate.

There should be no planned overflow to the sump. All surfaces should be graded away from the sump's edge and drainage from the pad or other upslope areas should be diverted around the sump to downslope areas. A minimum of a one meter freeboard should be maintained. To prevent leakage of toxic fluids into the soil and downslope surface or groundwater, the walls and base of the mud sump must be rendered impermeable. Several methods are suitable, depending on the situation. All basically require soil compaction with various types of liners.

1. Impervious clay - the most common type of lining. Advantages are that it conforms to the sump shape, it is self sealing, and it is not subject to accidental rupture should pipe, tool, or drill rods be accidentally dropped into the sump, or should earthquake movements occur.
2. Soil/cement lining. Quick lime or pozmix cement, about 10 percent by volume, should be added and thoroughly mixed into selected soils having a suitable clay content. The mixed material should then be spread throughout the sump area in 150-millimeter layers and compacted. This procedure should be repeated until a 300-millimeter-thick minimum, impervious lining is created.
3. Plastic (PVC) lining. When lining is plastic, precautions must be taken to prevent its puncture. The surface of the sump must be smooth. Rocks and sticks must be removed. A layer of sand lining may be added to the smoothed surface. The plastic is laid down in

a single sheet at least 20 mils thick and covered with an additional several inches of sand, silt or clay. Additional precautions are necessary during use of the sump to prevent lining puncture. Support material (e.g., gravel surfaced with a few large rocks) should be provided for the takeup and discharge lines. Tools, pipe and other such objects must be prevented from falling into the sump.

During the time that the sump contains toxic mud and drilling wastes, a strong fence should be built to prevent animals from getting to the toxic material. When the time comes to bury or remove the drilling muds and turn the sump into a safe watering area, the fence can be removed to allow free access.

A special determination should be made of the availability of equipment and personnel necessary to clean up spills from sump failures, and a contingency plan prepared.

Mitigation. During drilling operations and prior to disposal, there should be a detailed chemical analysis of drill mud composition. If a risk from toxic substances exists, the mud should be disposed of with extreme care, and either hauled to an appropriate dump site or left in the sump, provided the sump was constructed to be essentially impervious. If analysis reveals that the muds are not toxic, they may be disposed of in some beneficial manner, perhaps on the surface of a gravelled road. The road should be inspected beforehand, and if the road bed material has a high proportion of fine clay content already, the spreading of bentonite will probably have no beneficial effect.

Most localities will have requirements regulating such disposal sites as mud sumps. In addition, the surface management agencies usually will have suggested specifications appropriate to the locality, as will the Environmental Protection Agency's guidelines on toxic waste disposal.

Activity - Deep Drilling

Description. Drilling entails the operations associated with constructing the well hole down to the heat source. Heavy-duty oil well drilling equipment is used. A tower 27-36 meters high is used to raise sections of drill pipe successively into position and to attach to the pipe being placed in the ground as the rotary drilling bit penetrates. At the base of this tower is a working platform about 3 meters from the ground. Power units (up to twelve 175-horsepower,

heavy-duty diesel electric generators) are adjacent to the platform and are operated continuously for the entire process. Pumps for handling mud and other drilling accessories are beneath the platform. All machinery is portable, transported by semi-trucks, and can be removed or set up in 1-2 days.

Drilling muds lubricate the drill bit, cool the reservoir formation, transport drill cuttings to the surface, seal the side of the drill hole, and prevent blowouts. After the drilling mud circulates down the drill hole, it returns to the surface and enters an open sump. Here it cools, and the cutting material settles out before being recirculated and reused in the drill hole. This mud may contain toxic materials (caustic soda and other additives) and following completion of drilling must be either disposed of in place or transported to off-site dumps.

In certain situations, such as hot, dry steam formation, air may be used instead of drilling mud to cool the bit and bring cuttings to the surface. The air-steam mixture returns to the surface, where cuttings are separated in a "particle separator", and the air-steam mixture is vented to the atmosphere through a muffler.

A crew of about 20-24 is normally lodged off-site, transported by bus or car, and will operate the equipment for 40-60 days.

Type of Impact Expected

Off-site		On-site	X
Long-Term	X	Short-Term	X
Geothermal	X	Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	X

Impact. Impacts will be covered one by one. The most serious is an accidental blowout. Pressure stresses occasionally lead to containment failure of a well. Blowouts can happen in several ways: steam may escape through weak rock below shallow casing; landslide movement can shear off the casing; weak casing may fail when subjected to high pressures; well head equipment may break away from the casing; steam may escape along the outside of the casing if it is not adequately cemented; insufficient cooling during drilling may allow steam to escape upward through and around the drill stem. Improvements in technology, such as well head blowout protection equipment, increased casing strengths through new metal alloys, and more careful monitoring of potential danger signs, have greatly reduced the risk of blowouts. However, the potential for blowouts with attendant locally disastrous results still exists.

Photo Courtesy Bonni Kennett

Blowout at Beowawe, NV., caused by vandalism.

Blowouts can be small, affecting only small areas on the drilling pad, or they can be large, forming craters as large or larger than the entire drilling pad. The physical force of the blowout may in itself destroy vegetation on several acres of adjacent land, spreading soil, rocks and other types of debris around the landscape, and also cause sump failure with its own attendant impacts. In addition, the blowout will be accompanied by an uncontrolled release of the full flow of geothermal fluids, with the impacts discussed in the Well Testing section. The duration of the release depends on many factors, such as depth of the blowout in the well casing.

Mitigation. Blowouts can be prevented by a) proper site selection, b) using adequately strong casing material, c) well head blowout prevention equipment, 3) appropriate drilling procedures (maintaining proper drill mud temperatures, etc.). There can be rapid control of blowouts by providing advance planning for equipment and trained personnel. Thorough, timely cleanup operations of toxic spills resulting from a blowout can lessen impacts.

Impact. There may be loss of surface flows from hot springs and geysers, and consequent loss of unique aquatic species. Surface or groundwater may be polluted by release of toxic substances from operations (e.g., accidental spills of oil, detergents, drill mud additives, etc.); toxic substances contained in the resources; or mixing of deep geothermal fluids with shallow groundwater. The three primary environmental factors to bear in mind are the topography, the presence of surface waters, and the permeability characteristics of the soil and geological strata between the surface and groundwater.

Mitigation. Surface management agencies will usually have suggested specifications appropriate to the locality as will the Environmental Protection Agency's guidelines on toxic waste disposal. The USGS will issue specific casing and lining measures to prevent connection of the groundwater system with the well.

Impact. Significant atmospheric impacts are air and noise pollution. Causes will vary considerably depending on the stage of the operation and on the nature of the resource encountered.

Sources of air pollution from drilling operations include:

- Exhaust from diesel generators.
- Dust and exhaust from vehicles traveling on the access roads and drill pads.
- Volatilization of gaseous substances dissolved in the liquid resource or entrained in steam.

Air pollution is potentially greater if a steam resource is encountered. Sources include:

- Moisture from the steam.
- Dust and rock fragments (drill cuttings).
- Gaseous contaminants contained in the steam.

Gaseous contaminants are the only source of significant impacts. Under atmospheric inversions, certain contaminants in the steam resource could reach undesirable levels near operations. Though other fields may prove to have different characteristics, based on BLM calculations (1973) deep drilling at The Geysers geothermal field contributed the following materials to the atmosphere:

- Moisture of the steam itself: 1,800 tons/day.
- Dust and rock fragments from drill cuttings: 25.8 tons/day during drilling for 10 days.
- Gaseous contaminants contained in the steam: 34.8 tons/day.

The primary components of the gaseous contaminants are:

Constituent	Tons/Day
CO_2	22
H_2	5.2
CH_4	5.3
N_2	1.2
H_2S	.59
NH_3	.45

In addition to these, there may be traces of other substances such as CO, HF, H_3BO_3, Hg, A, Ra, and Rn in gaseous, vapor or particulate form. These air contaminants may affect plant and animal life, and may contribute an offensive odor - chiefly H_2S - which may disturb humans at considerable

distances. A chief concern may be H_2S, which could have a toxic effect locally on plant and animal life. (The odor of H_2S may also be highly unpleasant to humans over a considerable area.) CO, B, Ra and Rn may also be components with possible adverse impacts upon living organisms. Dust may affect plant viability.

Mitigation. Steam and gases venting to the atmosphere should be analyzed for their constituents and appropriate control methods applied. (Normally this will be a removal of H_2S by scrubbing techniques.) Dust control can be instituted.

Impact. Sources of auditory impacts are commuter and supply vehicles, diesel generators (6-12 175 hp engines), air compressors, and vented gases. Though GRO Order #4 provides guidance for noise control, the impact of noise on wildlife is not clearly understood, and special problems may be associated with unique wildlife types. Aural efficiency of owls, deer, rabbits, squirrels, and others whose defense or hunting mechanisms are dependent on sound and nesting raptors may be affected. Noise may alarm and disperse animals at critical stages of their life cycles; the noise (as well as motion and activity) of drilling may cause some species, particularly large animals, to leave though they may return after the 40 to 60-day drilling operation. (Subsequent activity of testing and pipeline construction will not interfere with deer and many small animals with nocturnal feeding habits.)

Table 36

COMPARISON OF NOISE LEVELS BETWEEN THE GEYSERS AREA AND OTHER SOURCES

Geysers Area	Level	Distance*
Source		
Drilling operation (air)	126 dBA	7.7
Drilling operation (air)	90 dBA	457
Muffled testing well	100 dBA	7.7
Muffled testing well	65 dBA	457
Steam line vent	100 dBA	16.3
Steam line vent	90 dBA	76.3
Comparative Levels		
Jet aircraft takeoff	125 dBA	61
Threshold of pain	120 dBA	
Unmuffled diesel truck	100 dBA	16.3
Street corner in a large city (average)	75 dBA	
Residential area at night (average)	40 dBA	

* In meters.

NOTE: Attenuated values are a result of distance only and do not consider variable factors such as topography, wind speed and direction, relative humidity, presence of structural barriers, and the frequency characteristics of the sound itself.

Mitigation. Tables 33, 34 and 36 contain examples of noise levels associated with some geothermal activities and for assessing their attenuation with distance from the source. Diesel engines for drilling rigs and producing wells should be muffled to decrease noise levels whenever possible. Drilling and construction should be timed to avoid periods of wildlife breeding and nesting. For example, drilling should be shut down during the breeding cycle of sage grouse, nesting activities of the peregrine falcon, antelope kidding, etc. This should follow a very careful biological survey of the area in question. Inspection of wildlife species lists and habitat requirements may uncover potential problems. If alternate sites are available for exploratory drilling, they can be used to avoid disturbing sensitive species.

Impact. Accelerated soil erosion can take place on-site from surfaces bored and compacted during site preparation. Undisturbed soils downslope will be subjected to runoff from drill pads and roads, and channeled runoff may reach high velocity flowing down fill-slopes, creating a significant impact. Construction coinciding with seasonal rains would maximize erosion hazard. Slope characteristics are important in assessing erosion potential, which would be negligible on level terrain.

Mitigation. See General Construction section.

Impact. Seismic and subsidence problems encountered during the operation of a producing geothermal field are not normally associated with limited exploratory projects.

Mass wastage problems (landslides and soil slumpage) are associated with unstable geological formations or surface soils. Severe landslides or soil slumps can cause direct damage to the well drilling operation, leading to blowouts, or other problems such as sump failure, which are discussed later.

Mitigation. The danger of mass wastage can be greatly alleviated by proper site selection. Geological and soil surveys should be conducted to identify potential geological hazards. Danger areas should be avoided, or appropriate protective measures should be taken to avoid mass wastage problems.

Impact. Operations generally result in complete destruction of vegetation over .4-.8 hectars for each drill site. Any new road construction will, of course, destroy vegetation also.

If the well is successful, most of the drilling site will remain in use for continuing drilling, construction and storage of materials. Roads seldom, if ever, are put back into natural condition, and so will repeat a disturbed vegetation pattern.

Mitigation. If a drill site is abandoned, it should be revegetated. If roads are not needed to service other active wells, they may remain for possible future use (hunting, fishing, recreation) or can be regraded and revegetated if public use is incompatible with sensitive resources. During revegetation, there will be a change in the mix of wildlife habitat, and thus a possibility for a change in the wildlife mix. Habitat for browsing species will be enhanced by young sprouts, and, when revegetation is natural, by the increased variety of vegetation caused by cleaning of the land surface.

Activity - Well Testing, Shut Down, or Abandonment

Description. After completion of the well, productive potential must be tested. The nature of the resource determines the type of testing required. Testing involves the discharge of gases into the atmosphere, and in the case of a liquid resource there will also be a liquid discharge into the sump, a reinjection well, or other designated areas.

Sources of air pollution will be moisture from steam; dirt and rock fragments caused by well-bore sloughing (during venting of steam resource only); gaseous contaminants; and volatilization of gaseous components of the liquid.

If the resource is a liquid-dominated geothermal field, fluid from the well head will be pumped or flow into a flash chamber where 15 to 20 percent of the resources mass is flashed to steam and discharged to the atmosphere. The remaining 80 to 85 percent is discharged into the mud sumps for storage. Measurements are made on well head pressure, enthalpy, mass flow, rates of changes of mass flow, ionic concentrations, total constituents analyses, etc. Geothermal fluid not flashed to steam must be stored on the site or discharged to the surface drainage system. Reinjection is not usually possible at this time, as two wells are required, along with a more complete knowledge of the resource. Since flow rates can range from 5.7 to 7.5 cubic meters per minute and the testing time can range from 10 to 72 hours, storage may be necessary for as much as 34,100 cubic meters.

These tests are preliminary and are not the full-scale production tests needed to fully assess the potential of the geothermal resource. Detailed production testing is conducted later in conjunction with other test wells, but before plans for full field development are initiated.

Testing is entirely different for a dry steam resource. The steam is allowed to vent to the atmosphere through mufflers for about 24 hours, during which the necessary measurements are conducted.

Determination of the well's productive capacity will lead to three possible courses of action:

1. Successful liquid resource: The well will be entirely shut down, pending further drilling leading to development of a producing geothermal field. At that time, the well would be reopened as part of the production unit.
2. Successful vapor resource: The well would be shut down to a small bleeding level of vapor flow necessary to prevent condensation in the well bore. It would remain at this level until the field is developed, at which time it would become part of the production unit.
3. Unsuccessful: The well will be used for several types of geothermal investigations of temperature gradient, etc., then filled with cement according to regulations and abandoned.

After drilling has been completed, there are several operations for either subsequent use or site abandonment: regrading of excavated surfaces, removal or covering of sump material, and the construction of drainage systems to mitigate future erosion. Such operations take place whether or not the site is to be used for future production.

Type of Impact Expected

Off-site		On-site	X
Long-Term	X	Short-Term	X
Geothermal	X	Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	X

Impact. The most significant impacts from the discharge of effluent from geothermal wells are associated with the effects of salts and heavy metals and other toxic substances on vegetation, wildlife and water sources. In the case of exploratory drilling and testing, the duration of such discharges would be short and most impacts would be localized and short term.

Still, without enforcement of regulations, the tendency to test without adequate safeguards might be great, and there is a potential for the discharge of toxic effluents (high mercury, boron, or arsenic) before they have been identified by thorough chemical analysis. Toxic discharges could have serious long-term, regional effects through contamination of surface or shallow groundwaters. If the unflashed liquid portion of the fluid is discharged to the surface drainage system, it may enter the groundwater body through infiltration in dry stream beds, or it may travel as a hot and chemically loaded slug of water passing through aquatic habitats. This could cause drastic one-time alterations in these habitats by killing many organisms. Long-term effects may result if important species are destroyed by this discharge. This effect should be lessened further downstream, since the temperature would decrease because of heat loss to the stream bed and the atmosphere, and as dilution of the mineralized water occurs. (If the flashed portion of the fluid, or, for vapor-dominated fields, all of the resource, is vented to the atmosphere during periods of low altitude, high frequency inversions, the concentration of some constituents may affect plant vigor.) However, this is a short and site-specific impact.

Mitigation. No uncontrolled discharge of geothermal effluent should be permitted. Analysis is complicated, since concentrations of chemical constituents will vary from one well to the next in a single field, and will also vary over time in the same well. Only after a period of testing under full flow conditions (in excess of 6 months) should the surface discharge of geothermal fluids be considered. After the quality has been assured, it may be possible to use geothermal waters for beneficial purposes.

Steam from a dry steam well should be analyzed before production testing to determine the concentrations of its components. Problems associated with limited testing discharges are not normally significant. Under weather patterns of local inversions, etc., impacts may be greater. If a danger of toxicity exists, a contingency plan for cessation of testing operations during periods of local inversions should be developed.

One form of mitigation for the impact of a hot liquid discharge would be to store the effluent in the sump reservoir for future evaporative loss to the atmosphere. Mitigation may also take the form of timing the test for vapor-dominated systems, so that periods of atmospheric ventilation are utilized, and so that critical events in animal life cycles are avoided.

Mitigation for noise during testing basically requires adequate muffling equipment and is discussed in the Deep Drilling section.

Activity - Well Abandonment and Dismantling

Description. Unsuccessful exploratory wells must be abandoned. GRO Order #3 covers in detail the procedures required for well abandonment. In general the hole must be filled with concrete and above-ground structures removed.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	___	Physical	x
Direct	x	Indirect	x

Impact. Operations are not extensive or severe. A truck-mounted apparatus is necessary to pour cement into the well, and cement trucks and mixers must come onto the site. A tractor (fork lift or front end loader) may be required to load disassembled well head piping, etc. onto a truck. The only impacts expected are some compaction on the site, disturbance of wildlife due to human activity, the noise of machinery, etc. These are of such limited nature that special mitigation measures are not required.

Activity - Site Abandonment

Description. In addition to plugging the well (i.e., well abandonment) there should be a general clean-up of the entire site.

Clean-up operations require a crew of 1-3 persons, probably including a pick-up or dump truck and perhaps a tractor with front end loader. All litter, gear, toolsheds, etc., should be removed, and the area left as close to its natural state as possible.

Mitigation measures for revegetation are discussed fully under Well Testing, Shut Down or Abandonment and General Construction sections.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	___	Physical	x
Direct	___	Indirect	x

Phase: Full Field Development

When industry proceeds with full field development, new or extended roads will be built, and additional wells will be drilled, requiring new drilling pads, mud sumps, and storage and packing areas. Crew housing may be provided. Surface structures such as steam pipelines will be built to collect and deliver steam from a number of well heads to the particular user (power plant, industrial processor, agriculture, space heating, etc.). The operator must submit a Plan of Operation to the USGS along with APD if more deep wells are involved.

Activity - Construction of Roads, Drilling Pads, Mud Sumps, Buildings for Housing, Storage, etc.

Description. The main activity will be land clearing and leveling followed by earth moving and compaction for drilling pads and mud sumps. This will require heavy-duty equipment such as diesel-powered bulldozers, trucks, air compressors and road grading equipment.

Type of Impact Expected

Off-site		On-site	x
Long-Term	x	Short-Term	x
Geothermal		Non-Geothermal	x
Chemical		Physical	x
Direct	x	Indirect	x

Impact. With some variation for required well spacing, disturbed surface can reach 20 percent of the production field's total area, and operations will continue undefinitely. Impacts are discussed fully under General Construction and successive exploratory phases. The most serious effects of construction, apart from the direct destruction of habitat and physical displacement of animals, will be upon those species of animals which have some critical portion of their life cycle on or near the disturbed area. Breeding and nesting behavior in particular may be upset, and as a consequence serious population changes may occur, especially in the case of species with small breeding populations.

Mitigation. (See General Construction and exploratory phases.) Generally, no mitigation is possible for the modification of land, or for the physical occupation of the land by buildings, except for off-site habitat improvement for selected species. The measures available include reducing noise, allaying dust, and choosing a time of construction to avoid

Photo Courtesy Calif. Div. of Oil and Gas

Oblique view of a production field and electrical conversion plant at The Geysers, CA.

Photo Courtesy Calif. Div. of Oil and Gas

Steam collection system for one of the production fields at The Geysers, CA.

interfering with the sensitive portion of animal life cycles. Revegetation of all possible cleared areas and road cuts should begin at once, particularly on steep slopes. Runoff control structures should be designed and located so that water can be directed onto energy-dissipating rocks or ground. In some cases it may be feasible to pond this water in an impermeable or slow-draining basin, so that local wildlife may obtain a water supply. Full opportunity should be taken to consolidate storage areas and parking lots, and to minimize the number of roads. Buildings should be clustered whenever possible, and a single large building considered rather than a number of small buildings, whether scattered or clustered. Particular attention should be given to avoiding impediments to migration or critical social behavior, such as elk migration corridors or breeding areas.

Activity - Deep Well Injection

Description. Geothermal fluids are brought to the surface, heat is extracted and the fluids, now somewhat cooler, must be disposed of. One method, particularly suitable for geothermal brines, is to return the fluid, under pump pressure or gravity, to the reservoir. A point is chosen which will have no adverse affect on the geothermal resource, and which will, if necessary, give some protection against subsidence.

Type of Impact Expected

Off-site		On-site	X
Long-Term	X	Short-Term	X
Geothermal	X	Non-Geothermal	X
Chemical	X	Physical	X
Direct	X	Indirect	X

Impact. Reinjection will return the fluids containing toxic or undesirable salts to subsurface storage. But reinjection may introduce pollutants into groundwater if an aquifer is penetrated by the injection wells, and result in widespread contamination. Since about 20 percent of the original fluid volume is lost, the amount returned to the ground may require supplementation where there is danger of subsidence.

Mitigation. Contamination of groundwater aquifers may be avoided by casing the injection well to a depth that will prevent brine penetration of an aquifer.

Activity - Pipeline Construction

Description. As a geothermal field reaches full development, collection lines must be installed to bring steam and/or hot water from the wells to a central point for the planned use -- electrical power production, for example. There are usually about 15 to 25 wells at a spacing of 16 hectares per well.

Construction of pipelines demands heavy equipment to transport and handle the pipe, as well as to clear vegetation and make the land contour changes necessary to accommodate the pipeline. Pipelines are insulated and range from 10-30 inches in diameter; generally no single run exceeds 360 meters in length. Some trenching may be necessary, concrete foundation blocks must be placed, and road extensions constructed to, and along, the pipeline lanes. Low enthalpy water may use subsurface pipelines. There are small pipes for domestic or industrial processing.

Type of Impact Expected

Off-site	___	On-site	x
Long-Term	___	Short-Term	x
Geothermal	___	Non-Geothermal	x
Chemical	___	Physical	x
Direct	x	Indirect	x

Impact. The General Construction section and others cover similar impacts. Adverse visual impacts are especially characteristic of pipeline construction, and are pronounced when extensive pipeline networks are located on slopes. Clearing and grading for pipeline lanes not only result in prominent visual scars, but on slopes may cause erosion. Pipelines themselves may serve as barriers to animal movement, especially for larger species such as deer or elk and may prevent passage entirely or divert wildlife to other areas.

Mitigation. Mitigations for construction have already been discussed. Steam pipes should be located so that large animal passage is possible if migration or regular feeding trails are crossed. Expansion loops may provide access if the loops are vertical. Pipe burial may be necessary in rare instances.

Activity - Power Generation Facility Construction

Description. Electric power development such as that at The Geysers with 55 megawatt units requires 15-25 wells, pipelines and roads and the generating facility itself. This includes a generating building, cooling towers and an electrical switching yard. Along with piping between buildings, the surface area is about 5 percent of the total disturbed area for each development. This usually amounts to 4-6 hectares. Separate structures for storage and repair facilities may be necessary.

In binary cycle plants, heat is transferred from hot fluids to a separate fluid which drives a turbine. After the secondary fluid passes through the turbine, it is cooled by a third cooling fluid, usually water. After cooling, the secondary fluid is returned and heated again by the geothermal fluid. The cooling water must either be discharged to surface water in the area, be injected into the ground or otherwise placed so that the waste heat will not adversely affect the environment -- particularly the aquatic environment and associated organisms.

If dry or flashed steam from geothermal fluids is used to operate the turbine directly, dry cooling towers will be needed to dissipate heat from steam leaving the turbine. Approximately 113,600 to 132,600 cubic meters (30-35 million gallons) of water per day would be discharged to the atmosphere (evaporated) from a 1,000-megawatt field. This is the combined loss from the many power plants a 1,000-megawatt field may contain, as generator size varies from 15-100 megawatts.

Type of Impact Expected

Off-site	x	On-site	x
Long-Term	x	Short-Term	x
Geothermal	x	Non-Geothermal	x
Chemical	x	Physical	x
Direct	x	Indirect	x

Impact. See previous sections.

Mitigation. See previous sections.

Activity - Powerline Construction

Description. The main activity involved will be clearing of trees and vegetation for a 15-meter (50-foot) width.

The transmission lines per se will be supported by steel towers or poles 24-37 meters (80-120 feet) high. Towers must have concrete bases for each leg. Poles will require holes several feet deep. Supports will be spaced from 90-460 meters (300-1,500 feet) apart depending upon the height of the support structures and topography. Alignment of power lines will usually follow the shortest or most economical route.

Type of Impact Expected

Off-site	x	On-site	x
Long-Term	x	Short-Term	x
Geothermal		Non-Geothermal	x
Chemical		Physical	x
Direct	x	Indirect	x

Impact. Aside from general construction impacts, the lines may interfere with bird passage and may result in death or crippling for birds hitting the lines. Towers and poles may attract birds who use the structures as perches and make birds highly vulnerable to electrocution. Transmission line corridors also may facilitate the movements of animals, particularly deer and elk, especially if the corridors coincide with migration routes.

Mitigation. Towers and poles should be constructed at a height best suited to a minimum support and consistent with a minimum height of wires above ground. Power lines near waterfowl areas or on flyway routes should be avoided. Undergrounding should be used whenever feasible, keeping in mind the disadvantages of trenching equipment and soil disturbance needed to lay underground structures. Pole and insulator construction should be such that dangers of electrocution to raptors and other perching birds is eliminated or minimized (see Rural Electrification Bulletin, 1975, Suggested Practices for Reducing Raptor Losses on Powerlines). Routes should not penetrate the critical habitat of endangered or threatened species or the sensitive habitats of other valued species. This means avoiding any area where opening up dense stands of vegetation or encouraging access by humans or other species will result in interference with critical events in the life cycle of the species in question. Whenever possible transmission lines should follow existing roads or clearings. Related facilities such as transformer or switching stations should be appropriately located as discussed under the General Construction impacts and other sections devoted to structures. Undergrounding should be considered only when the benefits of removal of surface wires exceed the liabilities of ground disturbance and vegetation removal associated with

undergrounding. If oil is used as an insulator in undergrounding lines, there should be assurance that oil leaks from a ruptured line will be localized, and that there are provisions for shut-off of oil in order to prevent large-scale drainage from the line.

Vegetation clearing for firebreaks and prevention of short circuits may provide an "edge" effect of considerable magnitude, resulting in habitat interfaces of food and cover which may benefit wildlife. Revegetation as a mitigation measure for cleared ground may not be feasible because of fire or short-circuit problems. Fire-resistant vegetation or short, shrubby vegetation may be in order to stabilize the soil and to provide wildlife food and cover. Many power line corridors are kept free of "undesirable" vegetation through use of chemicals. Borates and arsenates have been used in the past, as well as defoliants in recent years; all of these should be avoided.

Activity - Operations and Maintenance of Field

Description. Generally, operation of a field increases activities already established: the collection of geothermal fluids from a number of wells and a resultant continuous noise; discharge of effluents and gases; discharge of geothermal fluids; operation of machinery; use of the geothermal resources (power plant, space heating, or agriculture or industrial processing); human activity -- all the characteristics of an industrial complex. The tying together of 325-400 hectares (800-1,000 acres) of land by steam lines, power lines, roads, etc. may result in drastic land use changes. While single wells and isolated roads will not necessarily prevent recreation, hunting, fishing, riding, hiking, or cattle or sheep grazing, the operation of the complex may demand that all other activities be excluded.

Type of Impact Expected

Off-site	x	On-site	x
Long-Term	x	Short-Term	x
Geothermal	x	Non-Geothermal	x
Chemical	x	Physical	x
Direct	x	Indirect	x

Impact. Impacts may increase in number and intensity. Changes in land use could affect wildlife indirectly, since the exclusion of cattle and sheep might reduce the competitive pressure on deer and elk, and subsequent economic development might cause loss of habitat and nongeothermal-related pollution of the environment. Large-scale operations may result in thermal modification of the air or water through waste heat

disposal. Fog (low clouds) may form locally when cooling tower or ponds are used, resulting in poorer light penetration adversely affecting vegetation and reducing transpiration and evaporation of water. As the number of wells increases, the chance of a blowout also increases. Blowouts may produce large quantities of toxic vapors and liquids, and would have considerably adverse effects upon water quality and upon fish, wildlife and vegetation directly.

The discharged liquids (cooled brines and/or condensate) may result in surface impacts, such as thermal modification of surface waters, toxicity to aquatic life, addition of dissolved salts to soil and water, changes in nutrient cycles, etc. If injected underground by pumping or gravity, these liquids may lubricate faults, leading in turn to seismic disturbances with possible damage to wells, structures, sumps, etc. The removal of geothermal fluids may cause a reduction in subsurface pressure, leading in turn to surface land subsidence, which would damage springs and seeps and could change ponding patterns. Surface streamflows and drainage may be modified -- all leading in turn to changes in vegetation because of the changes in hydrology.

Mitigation. Mitigations for these serious impacts have already been discussed. Large installations should be screened with proper vegetation. Some facilities could be painted dull colors instead of the usual highly reflective silver, and topographic features may be used to conceal pipelines and generating and storage facilities.

Activity - Field Abandonment

Description. At some point, due to lack of fluid recharge in arid regions, changes in the fluid chemistry, or changes in the value of geothermal heat, geothermal fields are expected to be abandoned. Wells will be shut down and the ultimate use (power plant, etc.) relocated. All structures and modifications such as wells, drilling pads, roads, buildings, steam lines, power transmission lines, storage and parking areas, etc., will now be shut down and removed, leaving highly disturbed land.

Type of Impact Expected

Off-site		On-site	X
Long-Term	X	Short-Term	X
Geothermal		Non-Geothermal	X
Chemical		Physical	X
Direct	X	Indirect	X

Impact. The impacts of field abandonment are related to the use of heavy equipment similar to that used in initial construction and field development. Residual impacts are related to large areas of raw disturbed ground, sumps, roads, former building sites, steam and transmission line corridors, etc. Visual blight, demolition materials, wastes of all types, noise, activity, and odors will all be present and must be minimized.

Mitigation. The primary effort in mitigation will be in reestablishing vegetation to cover visual scars, provide wildlife food and cover, and ensure soil stability. Terrain should be restored to natural contours whenever feasible. Topsoil, when saved from earlier land modification, should be returned, compacted, leveled and otherwise stabilized. It will be particularly important to control water runoff and minimize erosion, especially during early revegetation phases. Time should be allowed to stabilize soil before the rainy season. Vegetation may self-seed from adjacent undisturbed lands; however, usually seedlings must be transplanted if a quick return to brush or trees is expected. Natural plant succession on certain soils may require 50 to 100 years to return the area to its former undisturbed state. Fertilization and watering should be considered to accelerate reestablishment of the vegetation pattern.

All potentially toxic materials such as evaporated brines, drilling mud residues, etc., should be either removed to an approved solid waste disposal site or deeply covered so that no toxic components will leach and then enter surface streams or groundwater. If the components may be toxic to plants or animal life consuming the plants, then waste materials must be isolated and generally should be removed to an approved disposal site.

Structures will be removed. GRO Order #3 provides details on removing well materials and related abandonment procedures. Foundations should be leveled; all materials such as masonry, wood, metal, glass, plastic, etc., should be removed, and the area returned to a condition consistent with the undisturbed surroundings. Local plans for the area should be consulted, and no action taken which is inconsistent with the plans. Chapter should be used to identify possible actions for enhancement or for modifying the land for a new beneficial use such as agriculture, recreation, etc. Choice of vegetation (native or exotic), coupled with the possibility of using portions of the area for water storage, may offer a great opportunity for reestablishing native animal species and for increasing area productivity.

CHAPTER 5

MEANS OF WILDLIFE COMPENSATION AND HABITAT IMPROVEMENT

Even though the overall effect on wildlife and fish resources of most geothermal development will be adverse, in many cases there will be opportunities to create or improve wildlife habitat.

This section identifies measures suitable for improving wildlife habitat or compensating for loss of wildlife and fish resources. These measures will be related to the biomes in those parts of the United States having the greatest potential for geothermal development. In the western United States, these include the sagebrush-steppe, cool desert, hot desert, the Sierra-Cascade montane forest, and the southern temperate grasslands.

The concept of wildlife habitat improvement is to increase the carrying capacity of the land by management practices which will provide more and better food, cover, water, and living space. Carrying capacity is the number of animals which any piece of land will support or carry for extended periods of time without resource depletion. The amount and quality of food, cover, and water, which in part determine carrying capacity, are, in turn, determined mainly by: 1) the fertility of the soil, and 2) the use of the land (National Audubon Society, 1969). Carrying capacity can be increased by utilizing a wide variety of techniques aimed at altering a factor which may be limiting to the existing wildlife populations, whether it be lack of water, escape cover, nesting cover, or food.

The development of geothermal resources on federal lands will primarily involve as land managers the Bureau of Land Management (BLM), U. S. Forest Service (USFS) to a lesser extent, and the U. S. Bureau of Reclamation (USBR). Resource developments may offer opportunities to create or improve wildlife habitat on adjacent federal lands, and to provide examples for, and management assistance to, geothermal development on non-federal lands.

The requirements for habitat improvement and compensation for impacts on wildlife will provide federal and state land and resource management agencies with the opportunity to integrate habitat improvement measures with wildlife management plans for their respective land units, or for the wildlife

resources on private lands. Habitat improvement measures could be designed to conform with management objectives for wildlife resources established by the respective land management agencies. Each phase of geothermal development and production has different impacts on the environment, depending upon the potential of geothermal resources and varying relationships with other actual and potential resources. However, there will be an opportunity for the implementation of wildlife habitat improvement in each phase. Table 37 presents possible methods of habitat improvement applicable to the various phases of geothermal development.

Wildlife Habitat Improvement Methods For Geothermal Development

The improvement of wildlife habitat by various means is designed to create better food, water, cover, and space for wildlife species. Any program to compensate for habitat losses and to improve wildlife carrying capacity must be related to some basic principles:

"1. Projects must be justified according to biological needs based on intensive preliminary investigation. Proposed improvement practices should be evaluated as to their effect on other natural resource and land uses.

"2. Improvements should simulate natural conditions as much as possible. Native flora and fauna should usually be perpetuated.

"3. Vegetation manipulation projects should be designed, where possible, to follow natural topographical features as opposed to geometrical squares or strips.

"4. All projects should be evaluated at intervals to check whether they have accomplished the objectives identified in the preliminary investigation." (Yoakum, In: The Wildlife Society, 1971)

The following sections will deal with the various methods of habitat improvement that could be employed with geothermal development activities throughout the western United States. These methods are briefly outlined, and then related to five important western biomes --sagebrush-steppe, low desert, high desert, Sierra-Cascade montane forest, and southern temperate grasslands.

Table 37

FEASIBLE HABITAT IMPROVEMENT METHODS RELATED TO GEOTHERMAL PHASES AND DEVELOPMENT ACTIVITIES

Phase	Feature or Activity Warranting Compensation or Habitat Improvement	Feasible Habitat Improvement Methods
Exploration	Temporary access roads, Exploration sites	- Vegetation planting along roadways - Brushpiling
Test drilling and production testing	Permanent road network, sump construction, drilling	- Develop water source for wildlife use; guzzlers, watering areas - Sump development for nesting, feeding areas for waterfowl and marsh birds - Brushpiling - Fencing
Field development and power plant construction	Continual addition of wells, access roads and sumps, and power plant and powerline construction	- Revegetation - Develop roosting structures - Continue development of water sources, brushpiling, etc.
Full-scale production	No major additional features or activities beyond those of earlier stages	- Maintenance and operation of habitat improvement features
Field abandonment		- Rehabilitation of development sites: grading well sites, eliminating impermeable surface areas, and removing physical structures - Maintenance of improvement features

The listing of methods is not meant to represent the total potential for habitat improvement, but rather to familiarize the reader with some of the means to benefit wildlife resources, and how and where to obtain further information.

The improvement of wildlife habitat is a science calling for the expertise of knowledgeable biologists. Any program of habitat improvement will require the services of wildlife specialists, and the cooperation and guidance of state or federal resource management officials. Coordinated efforts by these biologists will include a plan for habitat improvement based on the particular habitats involved, the needs of the wildlife populations, and the management objectives of the land agencies.

Many of the concepts of habitat improvement can be applied anywhere throughout the western United States, since all habitat improvement techniques involve the basic needs of all wildlife species - food, cover, and water. However, the techniques and methods of applying concepts will vary from one biome to the next.

Water Supply

Much of the geothermally active lands of the western United States are in water-short areas -- high and low desert, and sagebrush-steppe. These biomes are characterized by a general lack of surface water. Any additional supply of good quality water resulting from geothermal development would therefore be a definite asset to wildlife. While such development may be unnecessary in parts of the west receiving high rainfall, water development may be a feasible and necessary undertaking in arid regions.

The feasibility of providing surface water supplies from geothermal reservoirs depends on the amount and quality of the geothermal effluent. Some presently productive fields, such as The Geysers, produce relatively good quality water, while others produce fluids having total dissolved solids as high as 25 percent. The nature and extent of the chemical constituents will determine the feasibility of water supply enhancement in any given area. The presence of dissolved gases such as hydrogen sulfides and ammonia in large amounts, as well as solids such as mercury and barium, may limit the uses to which geothermal fluids may be put. For any geothermally developed area, it will be necessary to evaluate on a case-by-case basis whether or not a water supply can be satisfactorily developed for wildlife use.

Some presently developed water supplies associated with low-enthalpy shallow geothermal sources in California are used for stock watering and domestic hot water -- two uses which certainly warrant good quality water. Fresh water supplies from deep geothermal wells could be developed whenever test drilling yields only freshwater and no developable geothermal source, or whenever a deep producing well passes through a high quality aquifer. A suitable water source would also be provided if a desalination system were associated with geothermal power development, such as in the Imperial Valley of California.

Intermittent sources of water represent another possible means of providing a source for wildlife use.

Water Developments

Watering Holes. Watering holes are open basins, natural or man-made, and are generally the center for wildlife activity. Usually water to these developments will come from surface runoff and not from geothermal sources. Unless such a supply is continuous, evaporation and uptake by vegetation may cause increases in salinity over the years.

Springs and Seeps. Under natural conditions, some geothermal fields may have fluid escaping to the surface through springs or fumeroles. If these water sources are free from high concentrations of dissolved solids, they may become popular watering areas for wildlife.

Water Catchments and Gallinaceous Guzzlers. Water catchments and gallinaceous guzzlers are another water supply development technique which can be used to enhance the wildlife habitat of geothermal sites. Water catchments are self-filling watering developments which can be either in the form of large sumps or subsurface tanks which are filled by a supply of water collecting on an apron and draining directly into the tank (guzzlers). Guzzlers are particularly useful in the hot and cool desert biomes.

Direct Use of Geothermally Heated Water. Geothermally heated water from fields in the colder climates may be of benefit to waterfowl by keeping water areas free from ice; however, such a program should only be undertaken after a full evaluation of the ramifications of maintaining ice-free habitat for waterfowl and other wildlife.

Photo Courtesy Calif. Dept. of Fish and Game

This quail guzzler is a popular watering spot for quail. Notice the rain collection apron to the left, the fencing to exclude livestock, and brushpiles to provide some escape cover for quail.

Reservoirs. A reservoir is a water impoundment in a drainage way, such as a seasonal or permanent stream. Such a development may not necessarily be associated with water produced by geothermal development, but may instead be in a natural watershed.

Costs of Water Development

- Gallinaceous guzzlers: $1,500 including installation
- Spring development: $150.00

Major Sources of Information for Water Development

1. U. S. Bureau of Land Management. 1964. Water development: Range improvements in Nevada for wildlife, livestock, and human use. Reno, Nev. 37 pp.
2. ----------. 1966. Polyethylene lines for pit reservoir including trough and fencing. Portland Service Center, Portland, Oregon. Tech. Notes p712C. 4 pp.
3. Glading, B. 1947. Game watering devices for the arid southwest. Trans. N. Amer. Wildl. Conf. 12:286.
4. Halloran, A. F. and O. V. Deming. 1956. Water developments for desert bighorn sheep. U. S. Fish and Wildlife Service, Washington, D. C. Leaflet no. 14.
5. Hamilton, C. L. and H. G. Jepson. 1940. Stock water developments: wells, springs and ponds. USDA Farmer's Bulletin no. 1859.
6. McLean, D. D. 1962. Water developments for upland game birds. Dept. of Fish and Game Mgmt. Leaflet no. 5.

Cover Improvement

Any compensation for habitat loss because of geothermal activities will require the improvement of remaining wildlife habitat equal to the loss which resulted from development. Changes and improvements in wildlife vegetative cover represent a potential means of increasing the carrying capacity of an area. Methods of improving cover for wildlife include construction of brushpiles, development of hedgerows, ground nesting sites, and natural and artificial roosting sites. The natural vegetation found on the lease site will determine the types of cover development feasible.

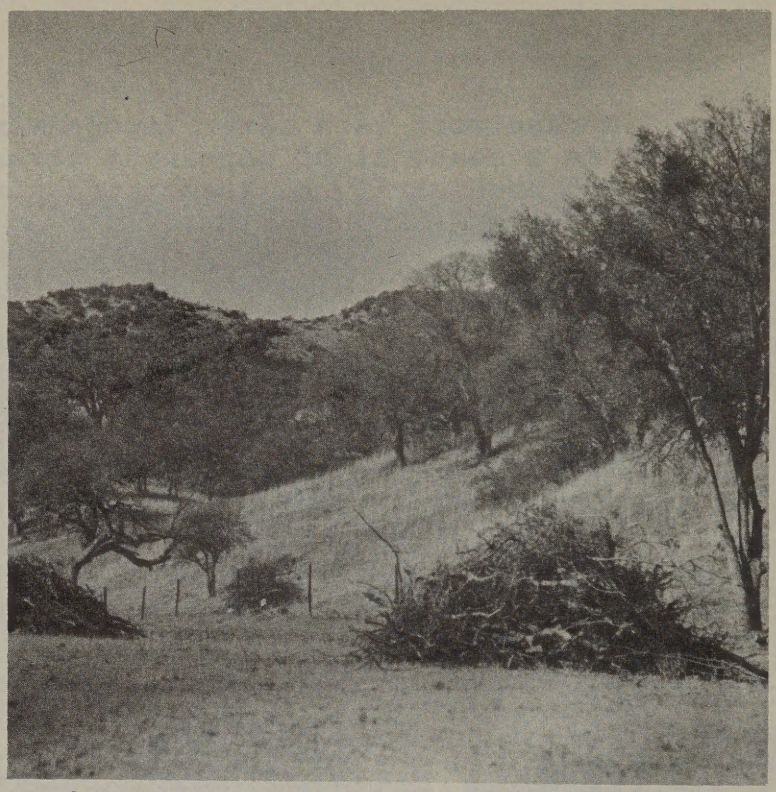


Photo Courtesy Calif. Dept. of Fish and Game

Brush piles provide escape cover for birds and small mammals.

Photo Courtesy Calif. Dept. of Fish and Game

This hedgerow of Atriplex creates habitat diversity and food and shelter for wildlife.

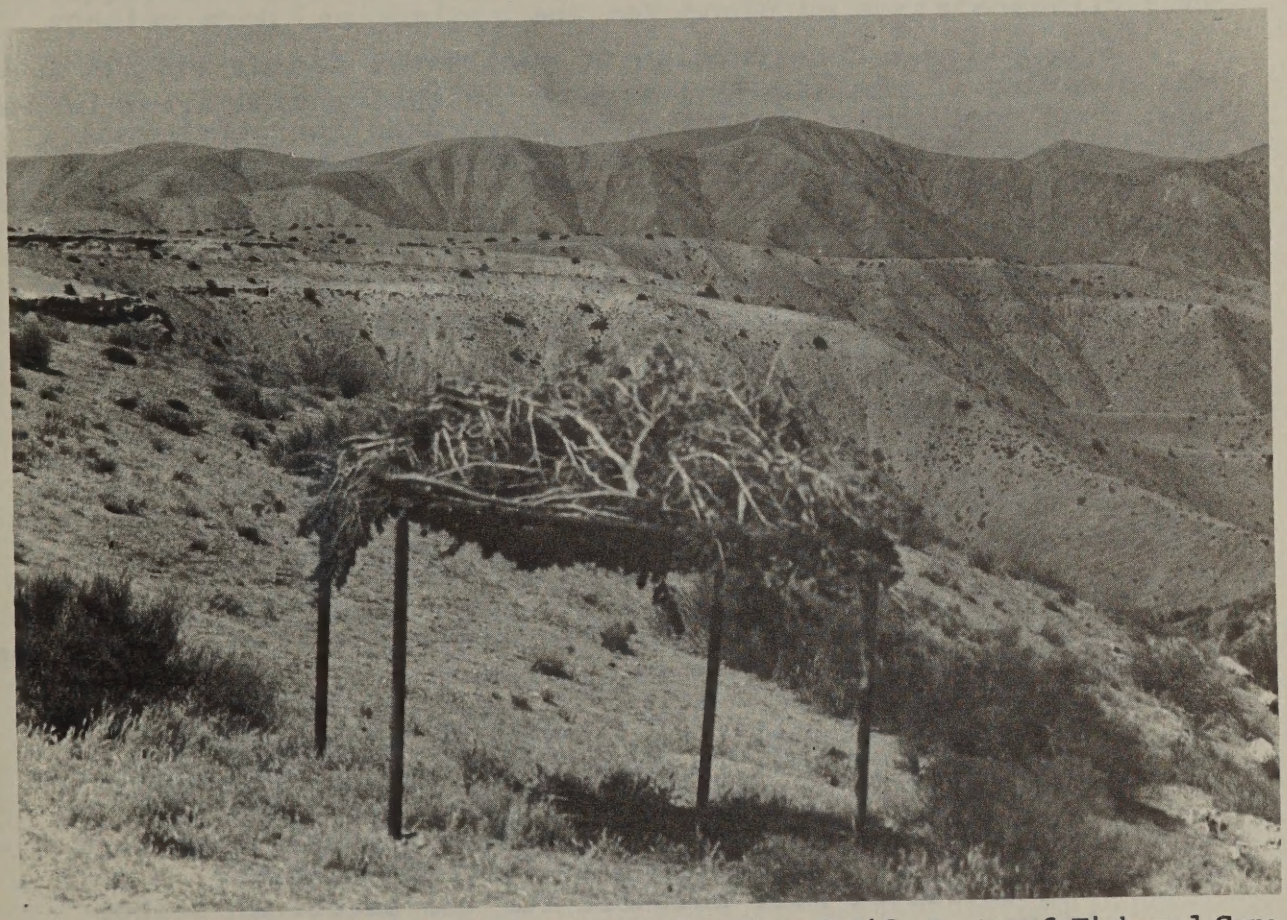


Photo Courtesy Calif. Dept. of Fish and Game

Artificial roosting sites may be useful in areas where little cover is available elsewhere.

The technique of utilizing brushpiles for habitat improvement would be applicable throughout much of the west, but would be of greatest benefit in areas lacking sufficient cover diversity, such as in southern temperate grasslands and some hot and cool desert areas.

Cover Developments

Brushpiles. Construction of geothermal fields will entail the clearing of the vegetative cover of substantial areas of land. When such vegetative stripping is undertaken for geothermal development, brush could be taken offsite for construction of brushpiles.

Hedgerows. Hedgerows and living fences provide cover and food supply to gamebirds, songbirds, and small mammals. Good areas for development of hedgerows are along dry washes and stream banks and also along the sides of access roads. The plant species used should be of high nutritional value for wildlife, drought resistant, highly adaptable to the habitat (preferably native vegetation), and should be selected for ease of maintenance. The fencing of hedgerows from cattle and deer is essential to ensure plant establishment.

The plant species suitable for hedgerows will vary throughout the west. The following is a list of several species that may be adaptable in several biomes.

- Atriplex (saltbush) - A. polycarpa, A. canescens, A. lentiformis, A. confertifolia. Highly adaptable to dry climates with less than 5 inches of rainfall. Suitable for cool and hot deserts, southern temperate grasslands. A. canescens is the most tolerant to cold and therefore most suitable for the sagebrush-steppe biome.
- Russian olive (Elaeagnus augustifolia) - a plant adaptable to high alkaline soils of the sagebrush-steppe, but adaptable also to the temperate grasslands biome and Cascade-Sierra Montane forest.
- Serviceberry - (Amelanchier sp.) - this shrub has a wide range of usefulness on a variety of sites, from dry to moist. Useful in sagebrush-steppe and portions of Cascade-Sierra Montane forest.
- Currant, gooseberry (Ribes sp.). There are numerous species of Ribes, all highly adaptable. Most are suitable for the Montane forest, sagebrush-steppe and grassland biomes where rainfall is greater than 10 inches.

Natural and Artificial Roosting Sites. Some bird species such as quail require perching and roosting sites. Providing such sites may aid in increasing the carrying capacity of a lease area and may satisfactorily aid in compensating for wildlife habitat losses from development. Wherever the conditions are proper, it may be possible to plant trees for perching and roosting. Many tree species require a substantial water supply in the desert or sagebrush biomes; however, some native species such as juniper and oak could be satisfactorily propagated.

Costs of Cover Improvement. For the costs for hedgerows see section on Costs of Food Production and Revegetation.

Brushpiles: Labor and equipment, bulldozer operation, $14.21/hr. Roost sites: Materials plus labor, $34-$50.

Major Sources of Information for Cover Improvement

1. Utah. Division of Fish and Game. 1968. Restoring big-game range in Utah. Publ. no. 68-3. 183 pp.
2. California. Department of Fish and Game. 1962. Improving land for California Valley quail. Game Mgmt. Leaflet no. 8. 11 pp.
3. ----------. 1968. Atriplex, a cover plant for wildlife. Game Mgmt. Leaflet no. 11. 11 pp.
4. MacGregor, W. G. 1950. The artificial roost - a new management tool for California quail. California Fish and Game, 36(3).
5. McMillan, I. 1959. An improved quail roost. Central California Sportsman, 19 (10): 349.
6. Giles, R. H. (ed). 1969. Wildlife management techniques. The Wildlife Society. 623 pp.

Food Production

The availability of food to wildlife is always of paramount importance. Any construction operation will destroy a certain portion of the available food supply and may in some cases lead to the starvation and/or loss of wildlife within the development area. Developers of geothermal fields should be familiar with methods of improving the food supply on their leaseholds.

Methods of food supply enhancement include: 1) the revegetating of roadsides and bare slopes with high-yielding varieties of shrubs and trees; 2) the release of desirable natural vegetation from competition by less desirable plants; and 3) the clearing of selected areas to create open space and stimulate growth of grass and forbs.

Photo Courtesy Calif. Dept. of Fish and Game

Brush manipulation and revegetating with more beneficial plant species will be an asset to many wildlife species.

Food Production Techniques

Revegetation. Revegetation will occur in areas disturbed by development activities. The planting of selected shrubs will help make up for food supply lost from development of a geothermal field. A few of the more common varieties of plants suitable for revegetation are presented in Table 38.

Release of vegetation. This process is accomplished by mechanical means, planned burning or chemical sprays. Some methods include anchor chaining, cabling, bulldozing, and scalping. Such practices can be useful in the Montane forest or sagebrush steppe biomes.

Clearing and seeding. This practice would be applicable to virtually all biomes of the west. The greatest amount of research has been done in the cool desert and sagebrush steppe biomes. Only species and strains of plants adapted to the area should be planted. Often it is necessary to repeat reseeding two or three years in a row to be assured of success.

Costs of food production and revegetation. Costs of habitat manipulation will vary with the method used and the area involved. Costs increase on rough or steep terrain.

- Brush manipulation: Crushing with a tractor and disc, $25 per hour. On good ground it is possible to do 1-1/4 to 1-1/2 acres per hour; on poor ground 1/2 acre per hour.
- Crushing with a ball and chain: $29 to $35 per hour or $18 per acre.
- Seeding with a rangeland drill: $25 to $35 per acre.
- Burning: $10 per acre, but may vary from $5 to $20 per acre (Allemand, pers. comm.).
- Cost of seed collected by hand from wildland stands is highly variable. Some of the more common species are:
  Bitterbrush: $1.60 per pound
  Currant, gooseberry: $7 to $15 per pound
  Russian olive: $0.80 per pound
  Saltbush: $0.50 to $1 per pound
  Wheatgrass: $0.65 per pound (Utah Division of Fish and Game, 1968).
- Bulldozer operator: $14.25 per hour.
- Small tractor operator: $13.26 per hour.
- Class I truck driver: $16 per hour.

Table 38

Adaptation and recommended use[1] of species for seeding in various precipitation and vegetation zones on lowland and mountain areas in the Intermountain region (Plummer et al. 1955).

GRASSES

Species	Lowlands				Mountain lands		
	Below 8 inches precipitation	8-12 inches precipitation	Above 12 inches precipitation	Salty soils	Mountain brush[2]	Aspen[3]	Subalpine
Sand dropseed	C	C	....	....	....	....	....
Bottlebrush squirreltail	C	C	....	....	....	....	....
Indian ricegrass	C	C	C	....	C	....	....
Russian wildrye	C	B	B	B	C	....	....
Crested wheatgrass (Standard)	B	A	A	....	B	....	....
Crested wheatgrass (Fairway)	B	A	A	....	A	C	....
Bulbous bluegrass	....	X	X	....	X	....	....
Bluebunch wheatgrass	....	B	B	....	B	C	....
Beardless wheatgrass	....	B	B	....	B	C	....
Pubescent wheatgrass	....	C[4]	A	....	A	B	....
Intermediate wheatgrass	....	C[4]	A	....	A	B	....
Western wheatgrass	....	C[4]	B	....	C	C	....
Beardless wildrye	....	C[4]	B	C	C	C	....
Big bluegrass	....	C[4]	C	....	C	....	....
Mountain rye	....	....	X	....	X	....	....
Great Basin wildrye	....	....	B	....	B	C	....
Tall wheatgrass	....	....	B	A	B	C	....
Tall fescue	....	....	....	B[4]	....	C	....
Bulbous barley	....	....	....	....	B	C	....
Blue wildrye	....	....	....	....	B	B	....
Bearded wheatgrass	....	....	....	....	B	B	....
Smooth brome (southern strain)	....	....	C[4]	....	A	A	B
Smooth brome (northern strain)	....	....	....	....	C	A	A
Slender wheatgrass	....	....	....	....	B	B	C
Mountain brome	....	....	....	....	B	B	C
Meadow brome	....	....	....	....	B	B	B
Kentucky bluegrass	....	....	....	....	X	X	X
Tall Oatgrass	....	....	....	....	A	A	A
Orchardgrass	....	....	....	....	B	A	C
Reed canarygrass	....	....	....	....	B[4]	B	B[4]
Timothy	....	....	....	....	B[4]	A	B
Meadow foxtail	....	....	....	....	B[4]	A	B
Sheep fescue (Sulcata)	....	....	....	....	....	C	C
Red fescue (sod-forming)	....	....	....	....	....	C	C
Subalpine brome	....	....	....	....	....	....	B
Winter rye	....	X	X	....	X	....	....

Table 38 (continued)

Species	Lowlands				Mountain lands		
	Below 8 inches precipitation	8-12 inches precipitation	Above 12 inches precipitation	Salty soils	Mountain brush[2]	Aspen[3]	Subalpine
LEGUMES							
Alfalfa	....	C[4]	B	....	B	C	....
Sicklepod milkvetch	....	C[4]	B	....	B	C	....
Chickpea milkvetch	....	C[4]	B	....	B	B	C
Yellow sweetclover	....	....	X[4]	B[4]	X	C	....
Strawberry clover	....	....	....	X[4]	....	....	....
Birdsfoot trefoil	....	....	....	....	C	C	....
Mountain lupine	....	....	....	....	....	C	B
Alsike clover	....	....	....	....	....	C[4]	C[4]
OTHER BROADLEAF HERBS							
Summercypress	....	....	....	X	....	....	....
Fivehook bassia	....	....	....	X	....	....	....
Palmer penstemon	....	X	X	....	X	....	....
Wasatch penstemon	....	....	....	....	X	X	....
Showy goldeneye	....	....	....	....	X	X	X
Common cowparsnip	....	....	....	....	C	C	C
Sweetanise	....	....	....	....	C[4]	C	C
SHRUBS							
Winterfat	C	C	C	....	C	....	....
Fourwing saltbush	C[4]	C	C	....	C	....	....
Antelope bitterbrush	....	C	C	....	C	C	....
Oldman wormwood	....	....	X	....	X	X	....
Blueberry elder	....	....	X	....	C	C	....

[1]A—Proved to be productive and widely adapted for seeding throughout the zone or type.
B—Valuable over much of the zone or type, but value or adaptation either more restricted or not as well determined as species designated A.
C—Value or adaptation more restricted than those species designated B, but useful in some situations.
X—Recommended for special uses or conditions, usually as pure stands.
[2]Applicable also for seeding openings in the ponderosa pine zone.
[3]Applicable also for seeding openings in Douglas-fir and spruce timber.
[4]Adapted only to better than average sites in the zone or type.

Source: The Wildlife Society, 1969. Wildlife management techniques, Chapter 14, J. Yoakum and W. Dasmann.

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Fencing

Much of the land in the western United States having the greatest potential for geothermal development is public domain managed by the BLM or USFS. A large percentage of the land is grazed by cattle and sheep on a lease basis. This is particularly true in the sagebrush-steppe, high and low deserts, and in portions of the Sierra-Cascade montane forests. This cattle and sheep grazing, in concert with the browsing activities of native deer and grazing and browsing of feral burros and horses, has created many overgrazed rangelands.

On geothermal lease sites it may be possible to substantially increase the productivity and carrying capacity of some undisturbed areas by fencing them off from domestic and feral animals. The combination of fencing, brush piling, and water development could, in many situations, improve habitat to pre-project conditions and possibly result in an even greater wildlife value.

Photo Courtesy Calif. Dept. of Fish and Game

Fencing and periodic grazing can be useful tools in improving wildlife habitat.

Costs of Fencing. Fencing costs are variable; however, the following estimates are based on May 1976 prices:

- Barbed wire: 1-1/2 cents/foot; $18.50/1,320 foot roll.
- Metal stakes: 5-1/2 foot; standard, $1.33 each, heavy duty, $1.67 each. 6-1/2 foot; standard, $1.53 each, heavy duty, $1.97 each.
- 6-inch by 6-inch mesh fencing, 4 feet wide by 330 feet long, $55.45.
- Rabbit fence, 1-1/2-inch square, 48-inch high by 100 feet, $103.95.
- Labor: $9.88/hour, plus 18 percent for fringe benefits.

Prices do not include costs for mechanical equipment.

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